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## THE TRIASSIC PORTION OF THE SHINARUMP GROUP, POWELL

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*Introduction.*—Among the great sedimentary formations or groups of the Plateau Province, described by Powell, Dutton, Gilbert, and others, that one named by Powell the Shinarump is today the least known and occasions the greatest difficulty in correlation. As I have recently attempted to correlate the formations of the Plateau Province with those of the adjoining mountain district of southwestern Colorado, the difficulties in regard to the Shinarump have come prominently to my attention, and it is hoped that a brief review of the subject may be of material assistance to geologists who attack the problem in future.

The Shinarump is the lowest of three formations or groups assigned by Powell to the Trias, the others being the intermediate Vermilion Cliff sandstone and the White Cliff sandstone at the top. The Triassic was thus supposed by him to embrace everything present in the great section north of the Grand Canyon between the upper Aubrey (Pennsylvanian) and the marine Jurassic.

Dutton and other writers have referred the White Cliff sandstone to the Jurassic, and this reference is no doubt correct, since the continuity has been established between this very well-marked formation and the La Plata sandstone of Colorado, which is in angular unconformity with the Triassic and the entire Paleozoic section (**4**).[2] The

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[2] Numbers in parentheses refer to the bibliographic list to be found at the end of this paper.

Triassic age of the Vermilion Cliff sandstone has not been directly questioned, neither has it been fully proven, and it will appear in the course of this discussion that there is some slight basis for the suggestion that it is lower Jurassic.

As for the Shinarump group, Walcott long ago found Permian fossils (**24**) in the lower beds referred to it by Powell and possibly Jurassic fossils (**4**) in the upper part, while a Triassic vertebrate fauna occurs near the middle of what Ward refers to the Shinarump (**26**). The question as to the real character, scope, and correlation of this group is then plainly one requiring further study and consideration.

The standpoint from which this review is written is that of several years' experience in the stratigraphic section of southwestern Colorado, with some information as to the gradual changes exhibited by the formations as they pass from the mountain slopes into the adjoining vast area of plain and canyon—the Plateau Province. It may be well to present in the outset the facts of major importance bearing on the topic under discussion and indicate frankly the tentative conclusions I have reached as to their application.

It has been established that the Dolores formation of the San Juan region of Colorado is of Triassic, and probably of upper Triassic age. An angular unconformity has been found below the Dolores by which the whole upper Paleozoic red-bed series and a part of the Pennsylvanian strata are locally cut out. No middle or lower Triassic beds have been found and none demonstrably Permian. The stratigraphic break below the Dolores is thus shown to be of much importance.

The Dolores formation has been traced from the mountains into the heart of the Plateau district along two lines of approach. The most important fact established is that the fossiliferous basal member of the formation extends west and northwest from the San Juan Mountains as far at least as Grand River, in Utah, where the angular unconformity below it is very marked, and 1,500 to 2,000 feet of probable Paleozoic beds are gone at some places. An overlap of the basal Dolores conglomerate from Permian (?) beds directly to the pre-Cambrian complex occurs on the western side of the Uncompahgre Plateau, in Colorado, where it was observed by Peale in 1875. The

fossiliferous lower strata of the Dolores have also been traced down the San Juan Valley nearly to the Glen Canyon of the Colorado, below the Henry Mountains.

While nothing similar to the Dolores fossiliferous conglomerate has been described from the original area of the Shinarump Group in Utah or Arizona, the discovery by Ward (**26**) on the Little Colorado River of the vertebrate fauna characteristic of the Dolores shows plainly that a correlation of great importance is to be anticipated when the requisite studies have been made.

In the literature of geological investigation in the Plateau Province, which is almost wholly of reconnaissance character, a certain bed or zone of strata in many widely separated localities has been called "the Shinarump conglomerate" and its identity in those places asserted. This has been done without much descriptive detail and chiefly on the basis of lithologic character. Now in the Dolores formation the lower zone, embracing all beds found to be fossiliferous, has also a most perfectly diagnostic lithologic phase. This is found almost invariably at the base of, and irregularly developed through, 200 or 300 feet of beds. Those who have worked in the San Juan region have come to apply the convenient field term "saurian conglomerate" to this diagnostic phase because one seldom searches in vain in it for teeth or bone fragments belonging to dinosaurs or to belodont crocodiles.

The peculiar lithologic feature of the "saurian conglomerate" is that it consists mainly of small round gray limestone pebbles, in many places almost pisolitic in appearance, though never showing the structure of true pisolite spheres, and rarely reaching one inch in diameter. The conglomerate is most irregularly distributed, with cross-bedding structure, through sandstone ledges from a few inches to perhaps thirty feet in thickness. The color of conglomerate-bearing ledges is often greenish gray and shales or sandstones of the same tones are common between them. More complete descriptions of the conglomerate zone are given in the Telluride and Rico folios (**1** and **3**).

The upper part of the Dolores formation is of very variable thickness in the San Juan region, owing in all probability to erosion in the ensuing epoch. It thickens westward and has been confidently correlated with the Vermilion Cliff sandstone of the Plateau Province (**4**).

The foregoing brief statement will, it is hoped, be sufficient to show the desirability of tracing the horizon represented by the basal beds of the Dolores formation through the Plateau country, not only to establish the base of the Trias but to discover the most favorable localities for the study of the older, and probably Paleozoic red beds, the full section of which is perhaps not yet known. According to present knowledge the horizon in question is not far below the Vermilion Cliff sandstone in the central and northern parts of the Plateau. In southern Utah and Arizona there is evidence of a decided increase in the thickness of the Triassic beds below the Vermilion Cliff sandstone, sufficient to warrant the suspicion that the true Shinarump conglomerate of the Shinarump Cliffs, while a thousand feet below that sandstone, may still be at the same horizon as the "saurian conglomerate" of the Dolores formation.

We will turn now to a scrutiny of the literature bearing upon the subject.

*The Shinarump conglomerate described.*—The term "Shinarump conglomerate" appears to have been used for the first time by Powell, in 1873, while describing the geologic structure and naming the topographic features of the district lying north of the Grand Canyon of the Colorado (**21**, p. 457, 458). Powell says that from the Grand Canyon northward one travels over Carboniferous beds to the first line of cliffs, one hundred to four hundred feet high.

> This escarpment is capped by a firmly cemented conglomerate containing many fragments of silicified wood, and over its surface are scattered many like fragments, and sometimes huge tree trunks, which are the remnants of rocks at one time overlying the conglomerate, but now carried away by erosion. Underlying this cap are variegated sandstones and marls. The whole group is probably of lower Triassic age.

In 1875, Gilbert, Marvine, and Howell, of the Wheeler Survey, published the results of their work in the country adjacent to the Colorado River, and refer to the Shinarump conglomerate as something defined by Powell. Their observations covered a wide territory, including that of the Shinarump Cliff, and there seems to be no doubt but that their references are to a single well-defined conglomerate stratum or bed.

Gilbert assigned to the Trias 2,500 to 3,500 feet of beds between the

marine-fossil horizon of the Jurassic and that of the "Permo-Carboniferous" (**11**). The upper, sandy portion of his Triassic section clearly includes the White and Vermilion Cliff sandstones, although they are not so named. The lower portion is described in general terms as "variegated, saliferous, and gypsiferous clays."

> In the midst of the clays is a bed of conglomerate. The lower shales were somewhat eroded by the current which spread it, as is shown by the inequality of the surface on which it rests. Its thickness is variable, and it is not universally present; but its persistence over large areas is nevertheless such as to excite wonder. In the conglomerate and in the superjacent clays are silicified tree trunks in great numbers. The fossil horizon discovered by Mr. Howell near Toquerville, and another that was noted south of Kanab, are lower than the Shinarump conglomerate (**11**, pp. 175, 176).

The Shinarump conglomerate appears to be definitely placed in several detailed sections published by Gilbert, between "variegated gypsiferous clays with silicified wood," above it, and "chocolate gypsiferous clays," below (**11**, pp. 158–60). On Paria Creek and at Jacob's Pool, Arizona, unconformities by erosion were noted below the conglomerate, but of no great extent, and Gilbert laid no special stress on the importance of the break indicated. Jacob's Pool is between Kanab Greek and the Paria, at the south base of the Paria Plateau.

Marvine speaks incidentally of "a conglomerate of siliceous pebbles, the Shin-ar-ump Triassic conglomerate of Powell" (**19**, p. 215). He apparently saw this bed only near St. George in Utah, near its western limit of outcrop, and on the Little Colorado, in Arizona.

Howell seems to have practically followed the Shinarump conglomerate for several hundred miles. He says:

> The conglomerate bed to which Mr. Powell has given the name Shinarump is a very singular formation. . . . . Having a maximum thickness at St. George of one hundred feet, it seldom exceeds forty or fifty to the east, but is coextensive, so far as I know, with the Trias of the Colorado Plateau. Occasionally it is little more than a coarse sandstone, and sometimes thins out to eight or ten feet, but never have I passed that horizon without seeing it. One of its constant features, almost as constant as its existence, is the great amount of silicified wood which it contains (**13**, p. 283).

Just below the ledge of the conglomerate, near Toquerville, in

southwestern Utah, a few fragments of lamellibranch shells were found by Howell. These were too imperfect for determination.

*The Shinarump Group.*—The comprehensive term "Shinarump Group" was proposed by Powell in 1876, in his *Geology of the Uinta Mountains*, for all the strata known to him between the upper Aubrey limestones and the Vermilion Cliff sandstone. Its Triassic age is assumed. The group is not described in much detail, the following section made by Powell "along the course of the Kanab in the winter of 1871" being the most complete statement given.

SECTION OF THE SHINARUMP GROUP, POWELL

| | Top | FEET |
|---|---|---|
| 11. | Bad-land sandstones, rapidly disintegrating; argillaceous; weathering in variegated hills | 800 |
| 12. | Conglomerate | 80 |
| 13. | Red bad-land sandstone; very friable, with much gypsum | 195 |
| 14. | Greenish-gray bad-land sandstone, with much gypsum, and rapidly disintegrating | 100 |
| 15. | Compact gray sandstone | 8 |
| 16. | Red sandstones and arenaceous shales; gypsum in seams and joints | 300 |
| 17. | Red and brown sandstone; rather thinly bedded, with many ripple marks | 250 |
| 18. | Conglomerate with angular and rounded fragments of limestone in a matrix of calciferous sand | 50 |
| | | 1,783 |

The conglomerate eight hundred feet below the top of the group is evidently the one elsewhere designated Shinarump conglomerate. Powell gives no hint that an unconformity had been noted by Gilbert beneath that horizon, but he repeatedly refers to the one at the base. The upper and lower parts of the group are described in very similar terms, and fossil wood is said to characterize the whole group. It is pointed out that, "The Shinarump conglomerate is usually very hard, and weathers in such a manner as to form hogbacks or cliffs, and the softer gypsiferous beds above, when carried away by rains, leave behind fragments of this silicified wood," etc.

It is evident that Powell did not suppose that his Shinarump Group contained Permian or other pre-Triassic beds. Neither he nor any other early observer commented upon the fact that if the Shinarump conglomerate contained worn pebbles of fossil wood

there was probably a considerable difference in age between the silicified wood of the upper and lower parts of the group.

Without detailed description and with no suggestion of variation in character, Powell affirms the wide extension of the Shinarump group in the following sentence:

> The variegated beds above and below the [Shinarump] conglomerate are seen in many places on either flank of the Uinta Mountains, and from time to time this horizon is brought up by faults or flexures in all the stretch of country which intervenes between the Shinarump Cliffs and the Uinta Mountains. [**23**, p. 54]. . . . . [With regard to the Shinarump conglomerate, Powell does acknowledge that it is not easily recognizable, toward the north about twenty feet in thickness, but increasing southward until it attains two hundred feet (**23**, p. 41).]

*The Shinarump as treated by Dutton in 1880.*—A treatment of the Shinarump group very similar to that of Powell was given by Dutton in 1880 in his *Geology of the High Plateaus of Utah* (**6**). The range given to the group is the same, and on account of the constancy of character few descriptive details are given. Dutton thus introduces the discussion of the Shinarump:

> Resting everywhere upon the Carboniferous of the Plateau country is a series of sandy shales, which in some respects are the most extraordinary group of strata in the West, and perhaps the most extraordinary in the world. . . . . There are especially three characteristics, either one of which would render them in the highest degree conspicuous, curious, and entertaining. First may be mentioned the constancy with which the component members of the series preserve their characters throughout the entire province. Wherever their proper horizon is exposed they are always disclosed, and the same well-known features are presented in southwestern Utah, in central Utah, around the junction of the Grand and the Green, in the San Rafael Swell, and at the base of the Uinta Mountains. As we pass from one of these localities to another, not a line seems to have disappeared, not a color to have deepened or paled. . . . . The constancy is, so far as known to me, without a parallel in any formation in any other region (**6**, p. 144).

Only slight changes in thickness and in constitution are admitted. The varied coloration of different beds and the architectural forms resulting from erosion are the other two marked characteristics.

The constancy in lithologic character, the wonderful coloring, and the peculiar architecture of erosional forms here emphasized, all avowedly pertain to the lower part of the group, recognized by Dutton two years later as belonging to the Permian.

The Shinarump conglomerate is said to be within "the transitional shales" of 550 to 750 feet thickness below the Vermilion Cliff sandstone—shales not described except as "monotonous." The conglomerate is said to "consist of fragments of silicified wood imbedded in a matrix of sand and gravel." Its thickness rarely exceeds fifty feet. "It occasionally thins out and disappears, but usually recurs if the outcrops be traced onwards, resembling the mode of occurrence common to the coal seams of the Carboniferous coal measures." It is indeed suggested that the conditions under which the conglomerate was accumulated "may have been similar to those attending the formation of coal." "The subsequent silicification of the wood" is regarded as remarkable and no possibility that any part of the wood may have been derived from earlier formations seems to have been entertained (**6**, p. 147).

*Walcott's section in the Kanab Valley.*—In 1879, as his first work in connection with the U. S. Geological Survey, C. D. Walcott made a careful section of the formations displayed so well in the Kanab Valley, from the lower Tertiary to the pre-Cambrian of the Grand Canyon. As a result of this study, Walcott announced in 1880 the discovery of Permian fossils in the beds between the Aubrey limestone and the Shinarump conglomerate, i. e., the lower part of Powell's Shinarump Group (**24**). He found a plane of unconformity by erosion above the Aubrey, as stated by Powell, and another below the Shinarump conglomerate, as noted by Gilbert at other localities, and a third in the intermediate beds. Permian fossils were found either side of the last break.

The unconformity below the Shinarump conglomerate was further described some years later (**25**) on the basis of new observations, but the full section of the Shinarump and superjacent formations was first published in connection with a discussion of the western Colorado red beds and their correlation, by myself (**4**, p. 484). For comparison with Powell's section, also in the Kanab Valley, and that of Ward, to be given later, it seems desirable to give the section made by Walcott from the Aubrey to the Marine Jura. This I am able to do through Mr. Walcott's generosity and kindness in giving me unrestricted use of his notes

SECTION IN KANAB VALLEY, UTAH, MADE BY C. D. WALCOTT, 1879

*Jurassic*

| | | FEET |
|---|---|---|
| 1. | White Cliff sandstone, massive, cross-bedded, light gray, broken into five principal belts by horizontal lines of bedding | 585 |

*Triassic*

| | | |
|---|---|---|
| 2. | Vermilion sandstone; cross-bedded, friable, readily disintegrating, forming the foothills and slope to the more compact sandstones at the northern end of Vermilion Cliff Canyon | 650 |
| 3. | Gray and reddish-brown, cross-bedded sandstone. Horizontal beds of varying thickness divide the mass into bands of from twenty-five to one hundred feet in thickness | 300 |
| 4. | Evenly bedded red sandstones; upper portion an indurated, dark-reddish-brown stratum; indurated layers alternate with more friable layers and shales beneath | 120 |
| 5. | Massive gray sandstone, cross-bedded; upper portion is a light-gray massive friable bed. The entire mass is subdivided into six principal beds by subhorizontal lines of bedding of a dark, more indurated sandstone. The beds are from twenty to eighty feet in thickness, and may be seen on many steep escarpments along the cañon | 310 |
| 6. | Solid, partially cross-bedded sandstone, changing from gray to various shades of red | 20 |
| 7. | Evenly bedded, light-red sandstone with a thin layer of intercalated gray sandstone | 20 |
| 8. | Dark-red sandstone; massive layers alternating with shale, which disintegrates and forms a sloping talus to the gray sandstone beneath | 180 |
| 9. | Light-gray sandstone | 5 |
| 10. | Bedded sandstone of various shades of red and gray. The layers of sandstone and their shaly partings are irregular in thickness. Scolithus borings occur in great numbers in a friable yellow sandstone. Fragments of vegetable matter and carbonized wood also were seen | 230 |
| 11. | Thin layers of sandstone, alternating with bands of fine argillaceous shale holding fish teeth and shells | 25 |
| 12. | Massive light-brown sandstone, broken up into thick layers | 50 |
| 13. | Alternating layers of sandstone and fine argillaceous shales with fish teeth, etc. | 25 |
| | A detailed section of 13 is as follows: | |
| | *a*. Light sandy layers with shaly partings | 7 |
| | *b*. Fine, smooth, arenaceous and argillaceous shales, drab brown to red with fillets of green. A few fish scales were found | 6 |
| | *c*. Fine-grained, light-colored sandstone, 2 to 4 feet in thickness | 4 |
| | *d*. Same as (*b*), only more fossiliferous | 8 |

| | | |
|---|---|---|
| 14. | Reddish-brown friable sandstone, broken into layers one to six feet thick, with shaly partings | 120 |
| 15. | Alternating bands of marls and shales, with layers of friable light and reddish-brown sandstone | 70 |
| 16. | Reddish-brown sandstone broken up into layers two to seven feet in thickness with a stratum of gray sandstone at the base | 20 |
| 17. | Arenaceous and earthy gypsiferous shales; marlites, purple, brown, bluish-green, and green, forming low, rounded foothills and slopes from the Vermilion cliffs to the Shinarump conglomerate | 650 |
| 18. | Gray conglomerate and sandstone. Conglomerate formed of small, agatized pebbles and holding silicified wood | 50 |
| | Total of Triassic | 2,845 |

UNCONFORMITY

*Permian*

| | | FEET |
|---|---|---|
| 19. | Dark, reddish-brown, shaly sandstones, passing into a massive evenly bedded sandstone twenty feet from the summit of the bed. Ripple marks and mud cracks occur in the upper part. Erosion has removed portions of the upper shaly stratum in places, leaving an irregular surface for the conglomerate above to rest on | 135 |
| 20. | Red, arenaceous shales with seams of gypsum ramifying through them in every direction | 105 |
| 21. | Gray, gypsiferous marls with intercalated arenaceous shales | 125 |
| 22. | Red gypsiferous marls, with a large proportion of arenaceous shales | 300 |
| 23. | Impure limestone, with small fossils—Rhynchonella, Mytilus, Bakewellia, Pleurophorus, etc. | 4 |
| 24. | Red gypsiferous marl | 15 |
| 25. | Impure shaly limestone with arenaceous and gypsiferous shales beneath. The sandy shales thicken into layers of from two to six inches in thickness. A stratum of red marl separates this from a somewhat similar band of limestone and shales beneath. On an outlying butte, two miles from the Shinarump Cliff, the entire bed is a shaly limestone. This stratum varies in thickness, as it was deposited on the uneven surface of the beds beneath. Numerous fossils occur both in the limestone and arenaceous layers—Discina, Rhynchonella, Bakewellia, Pleurophorus, Schizodus, Myalina, Rissoa, Goniatites, Nautilus, etc., found | 25 |
| 26. | Red gypsiferous marl with arenaceous shales throughout | 108 |
| 27. | Yellowish sandstone with red gypsiferous shale beneath, resting in eroded hollows of the Aubrey limestone | 37 |
| | Total of Permian | 854 |
| | Total of Section | 4,284 |

UNCONFORMITY

It is impossible to closely correlate Walcott's section with that given by Powell for the Kanab Valley (**23**, p. 53), except that the conglomerate, No. 18, is clearly the Shinarump conglomerate of Powell. It seems probable that No. 4 is the lowest member of the Vermilion Cliff group of Powell. Assuming that to be the case, it will be seen that fossil remains were found by Walcott at several horizons, in the members Nos. 10, 11, and 13, all in the upper part of the section. No fossils except silicified wood were noted in the lower 910 feet of strata assigned to the Triassic.

The fish remains obtained by Walcott in No. 13 of the above section were, at my suggestion, submitted to Dr. C. R. Eastman for examination, and he has published the following preliminary statement concerning them in connection with a discussion of the Triassic fishes of New Jersey.

> Of the few genera which are tolerably well indicated, such as *Pholidophorus* and several *Lepidotus*-like forms, it cannot be said that they evince anything in common with the Triassic fauna of the eastern states. Some resemblance is to be noted between the Kanab fish fauna and that of Perledo, near Lake Como, but the general aspect of the material collected by Walcott is much more suggestive of Jurassic than of Triassic relations. This might very well happen notwithstanding the horizon be definitely proved by stratigraphic and other evidence to be of Triassic age, as other instances of pioneer faunas and overlapping types are not uncommon. It does not appear, however, that the data thus far obtained warrants more than a plausible supposition that the Kanab beds are of Triassic age, their reddish color and relative position being consistent with what we should expect of rocks of that horizon. Accepting the evidence furnished by the fossil fishes at its full value, we shall have to regard the red beds of Kanab Canyon as belonging presumably to the Lias (**9**, p. 66 and **4**, p. 486).

The invertebrates obtained by Mr. Walcott in association with the vertebrates have been examined by Dr. H. W. Shimer, who has kindly given me (through Dr. Eastman) a report upon them. The material studied contains one indeterminable Ammonitoid fragment and two representatives of the Entomostracans. Of the latter, Dr. Shimer gives the following description:

ORDER OSTRACODA

*Candona? Rogersii Jones*

This species is exceedingly abundant on some bedding planes, the tests varying in length from .25$^{mm}$ to 1$^{mm}$. They show variation in form, some being

regularly oval, others obliquely pointed at one end. Notwithstanding their great abundance no separation of the two valves was discernable. Remains of this species occur profusely with *Estheria ovata* in the rocks of the Newark formation of Virginia and North Carolina.

ORDER PHYLLOPODA

*Estheria ovata Lea*

The specimens of Estheria are of different sizes, but all agree with the characters of this species where they are distinctly recognizable. The valves are rather strongly convex, slope forward from the umbo, and are prolonged on the ventral side posteriorly. Average specimens measure $4^{mm}$ in length and $3^{mm}$ in height ($\frac{3}{16} \times \frac{1}{8}$ inch). Some specimens show considerable resemblance to *Estheria minuta* var. *brodieana* Jones, but lack the greater development of the valves anteriorly, and their lesser development posteriorly.

This species is abundant in the Newark formation of the Atlantic border.

The fossil fishes of the Kanab section undoubtedly occur some hundreds of feet above the Shinarump conglomerate, but in view of the present meager knowledge of that fauna, and considering the character of the invertebrates, as identified by Dr. Shimer, as well as the stratigraphic relations of the section, it would manifestly be premature to accept at this time the qualified suggestion of Doctor Eastman and refer the fish-bearing strata and the higher beds of the Kanab section, including the Vermilion Cliff sandstone, to the lower Jurassic.

While Walcott found no fossils except silicified wood in the Shinarump conglomerate, there is evidence that a Triassic reptilian fauna occurs locally at least in that bed or near it. This has been established by the investigations of Ward, soon to be considered.

*Dutton's treatment of the Shinarump in 1882.*—In his monograph on the Grand Canyon district (**7**) Dutton accepts the reference of the strata between the Shinarump conglomerate and the Aubrey to the Permian, in accordance with Walcott's Kanab section. From his general treatment of the subject it now becomes clear that the description of the Shinarump Group given in the *Geology of the High Plateaus*, and especially the references to its wonderful coloring and constancy of character apply most particularly to the Permian portion, for that is the part best exposed in the "Permian Terrace," as Dutton still calls the one floored by the Shinarump conglomerate. The inconvenience caused by the distribution of this conglomerate,

interfering as it does with the harmony of broad architectural features and stratigraphic geology shown elsewhere in the section, leads Dutton to humorously complain that, "Somehow we cannot help thinking that the conglomerate has no business there, and that it ought to have been cut off at the base of the Vermilion Cliffs, or else it ought to be relegated to the Permian (**7**, p. 45)."

Dutton found, and specially notes, the erosional unconformity below the Shinarump conglomerate at Pipe Spring, a few miles west of the Kanab Valley (**7**, p. 80), and in discussing various unconformities by erosion noticeable in the Plateau district says: "Perhaps the most widely spread occurrence of this kind is the contact of the summit of the Permian with the Shinarump conglomerate which forms the base of the Trias. Wherever this horizon is exposed, this unconformity is generally manifest" (**7**, p. 211).

As to the character of the Shinarump conglomerate Dutton adds little, in the publication under review, to the earlier statements. His general characterization of it is as "a light-brown, coarse sandstone, here and there passing into a conglomerate" (**7**, p. 17). There never seems to be any question as to the ability to recognize the conglomerate horizon, with Dutton or other early observers. Commenting on the uniformity of strata of the whole Plateau section, Dutton remarks that: "The curious Shinarump conglomerate is the same in Pine Valley Mountains (near St. George), in the terrace at Kanab, at the base of the Echo Cliffs, and in the land of the Standing Rocks" (**7**, p. 208). The last-named locality is about the junction of the Grand and Green rivers.

On the geological map accompanying this monograph Dutton distinguishes the Permian from the Trias, and represents both extending south along the eastern side of the Little Colorado Valley.

*The Shinarump of Little Colorado Valley.*—All students of the northern and eastern borders of the Colorado Plateau agree in the general view expressed by Dutton on his map that the various formations or groups between the Aubrey and the base of the Cretaceous cross the Colorado Canyon near the mouth of the Paria River, and that their outcrops extend thence southeasterly on the northeast side of the Little Colorado Valley. From the statements of Marvine

(**19**, p. 215) it would appear that the exact horizon of the Shinarump conglomerate of Powell could be recognized on the Little Colorado near the main crossing of the early route of travel. Dutton reports it at the base of the Echo Cliffs. The only detailed investigation of the Shinarump beds of this valley thus far made has, however, produced results so different from those generally accepted, and especially at variance with Walcott's section as to require some discussion.

In connection with an examination of the "petrified forests" of northeastern Arizona in 1899 and 1901, Lester F. Ward made a study of the formations either side of the Little Colorado from the Aubrey (Carboniferous) to the Cretaceous. In a paper on the "Geology of the Little Colorado Valley" (**26**) Ward assigns all beds of this section to the Triassic, the Jurassic being entirely absent, in his opinion. This supposed Triassic system embraces 3,500 feet of strata divided by Ward into three parts, according to the following generalized columnar section.

SECTION IN LITTLE COLORADO VALLEY. WARD

| | | | FEET |
|---|---|---|---|
| Painted Desert beds | 15. | White sandstones | 100 |
| | 14. | Brown sandstones | 200 |
| | 13. | Variegated sandstones, regularly stratified, and brilliantly colored; the well-known Painted Cliffs | 800 |
| | 12. | Red-orange sandstones | 100 |
| | | | 1,200 |
| Shinarump Group — Leroux beds | 11. | Calcareous marls, sometimes worn into buttes | 200 |
| | 10. | Mortar beds, flint stones | 80 |
| | 9. | Limestone ledge, definitely stratified | 20 |
| | 8. | Sandstone ledge | 100 |
| | 7. | Variegated marls, argillaceous and calcareous with bones of belodonts, labyrinthodonts, and dinosaurs | 400 |
| Shinarump Group — Shinarump conglomerate | 6. | Conglomerate and coarse cross-bedded sandstones with clay lenses interstratified with gray argillaceous shales and variegated marls | 800 |
| | | | 1,600 |

| | | |
|---|---|---|
| Moencopie beds | 5. Dark chocolate-brown, argillaceous shales; saliferous | 200 |
| | 4. Argillaceous sandstones, soft, dark brown | 100 |
| | 3. Argillaceous shales, dark brown | 200 |
| | 2. Calcareous shales, white | 100 |
| | 1. Argillaceous shales, saliferous | 100 |
| | | 700 |
| Total | | 3,500 |

Limestone or Sandstone of Aubrey (Pennsylvanian)

In a later publication Ward revises the nomenclature of this section, speaking of the Moencopie, Shinarump, and Painted Desert *formations*, and under the Shinarump distinguishing the Leroux and Lithodendron members, the latter corresponding to the Shinarump conglomerate of his section (**27**, pp. 13–46). The term "Lithodendron member" refers to the fossil tree trunks, but is not distinctive, since these remains are also prominent in the Leroux member.

The discovery of a vertebrate fauna associated with fossil wood in a definite part of this section is certainly a most important contribution, but the systematic treatment by Ward is rather confusing as he does not attempt to harmonize his results with those of Powell, Dutton, Walcott, and others, which are, for the most part, not even referred to.

The Painted Desert formation, upon which, according to Ward, "the Cretaceous lignites and limestones lie unconformably" (**26**, p. 412) is clearly the equivalent of the Vermilion Cliff and White Cliff sandstones, although he makes no reference to earlier opinions or statements concerning the extension of these formations into the area where his section was made.

The Moencopie formation, on the other hand, corresponds in position and general character to the Permian beds found by Walcott in the Kanab section. Ward, however, found no fossiliferous limestones and makes no allusion to the work of Walcott; but if the Moencopie beds are Triassic they clearly belong in the Shinarump Group of Powell. In any case, Ward's use of Shinarump in a third sense, as a formation name for 1,600 feet of strata, seems unwarranted.

The correlation of eight hundred feet of sediments of variable character, grading into marls in some places, with the Shinarump conglomerate, is a procedure requiring clear justification by facts of

observation not to be found in Ward's papers. It is plain that Powell applied the name to a particular conglomerate seldom found to exceed more than one hundred feet in thickness and that all other writers I have cited, with the exception of Ward, have used the term for what they believed to be the same conglomerate. It appears to be impossible to locate the actual horizon of the Shinarump conglomerate in the Shinarump formation of Ward, yet, as the ensuing discussion will show, it is particularly important to ascertain the relation of the beds containing the reptilian fauna discovered by Ward to the Shinarump conglomerate of earlier investigators.

For reasons to be developed, it appears to me not improbable that the horizon of the Shinarump conglomerate proper is near the beds in which the vertebrate fossils were found, possibly at the base of the Leroux member of Ward. The statements of Powell and Dutton indicate that the conglomerate may become inconspicuous through thinning and that it may locally disappear as a conglomerate. Its horizon may be difficult of detection where the conglomerate phase is absent.

If it be assumed for the moment that the eight hundred feet of beds designated by Ward the Lithodendron member are below the horizon of the Shinarump conglomerate proper, there is reason to believe that those eight hundred feet of strata belong in truth with the Moencopie beds, the transition reported by Ward in Red Butte having the significance suggested for it by him. On this same assumption the Leroux beds of Ward fall into place as the lower Triassic of the Little Colorado Valley.

No fossils surely belonging to the Moencopie formation were found by Ward. Fossil wood is common in both members of the Shinarump. The celebrated "petrified forest" in which large prostrate silicified trunks are abundant represents more than one stratigraphic horizon. The so-called "upper" and "lower" forests are said to be in the Lithodendron beds, while the "middle" forest is in the Leroux member. As but one species of the silicified wood has been identified this abundant material is of little diagnostic value at present. The single species studied is *Araucarioxylon arizonicum Knowlton* (**15**), based on two fossil trunks collected by Lieutenant Hegewald, in 1879, of which the horizon of occurrence is unknown.

It seems to be assumed by Ward, as by others, that the occurrence of fossil wood throughout his Shinarump formation is an indication of its unity. But until these woods have been studied the correctness of that view is open to question. The presence of rounded pebbles of silicified wood in the Shinarump conglomerate has been asserted by several observers, and, if true, this fact alone must cause critical comparison of the fossil trunks occurring above and below this horizon.

The only tree trunks found by Ward in vertical position, as though in the place of growth, were in the Leroux beds very near the locality at which the best vertebrate remains were found, east of Tanner's crossing of the Little Colorado.

Vertebrate remains were found by Ward and Brown only in the Leroux beds and mostly in their lower portion. The principal localities from which they were collected by Brown for the National Museum are a few miles east or north of Tanner's Crossing, but they were noted at other places, including the "petrified forest." The material has been examined and partially described by Lucas (**17** and **18**), the forms identified by him being the following:

Two belodont crocodiles, *Episcoposaurus* sp.? Cope, and *Heterodontosuchus ganei*, Lucas, the type of which came from the San Juan Valley, Utah; *Metoposaurus fraasi*, Lucas, n. sp., *Placerias hesternus*, Lucas, n. sp., and *Palaeoctonus* sp.? Cope.

This fauna is in Lucas' opinion a distinctly upper Triassic one. He remarks that:

> Aside from the interest attached to the finding of this new species (of *Metoposaurus*) is the more important fact pointed out by Dr. Fraas (personally) that the genus *Metoposaurus* is characteristic of the Keuper of Europe, and that we have in these Triassic beds of Arizona, Utah, and Wyoming the same combination of belodont and labyrinthodont as in the Keuper (**18**, p. 195).

He might have added that the fauna is clearly present in the Dolores formation of Colorado.

Ward states that Brown found "a small number of shells and a few other invertebrates" with the vertebrate remains, but since their diagnostic value was questioned by Ward, they do not seem to have been submitted to a specialist for examination. Mr. T. W. Stanton informs me that the only invertebrates now in Brown's collection in the National Museum are Paleozoic brachiopods, corals, etc., in

pebbles. It is not certain that Ward referred to this material, the significance of which is not known.

Comparing the results obtained by Walcott and Ward in portions of the Colorado Plateau not many miles apart and where all earlier geologists have given the impression that the formations change but little from place to place, we find in fact remarkable differences. Walcott established an unconformity below the original Shinarump conglomerate; he discovered no vertebrate fossils in or near that stratum; but 910 feet above it, below the Vermilion Cliff sandstone, he found fish remains of unique character suggesting to the specialist Jurassic rather than Triassic affinities. Ward, on the other hand, finds at 400 to 800 feet below the Vermilion Cliff the Triassic reptilian fauna characterizing the basal portion of the Dolores formation through western Colorado and on Grand River; he noted no unconformity near this vertebrate horizon and does not recognize the Shinarump conglomerate of Powell, Walcott, and others. These discrepancies demonstrate that there is room for much further study of the Shinarump and associated formations in northern Arizona.

*The lower Trias of the Zuñi Plateau.*—The continuity of Mesozoic and upper Paleozoic formations from the vicinity of the Grand Canyon into northwestern New Mexico is a subject on which all geologists who have examined the region are agreed. In his report on the Zuñi Plateau, Dutton (**8**, p. 134) identifies 450 feet of strata as Permian, through the presence of fossils mentioned as *Bakewellia* and *Myalina* (without specific identification) and from the stratigraphic position of the beds between the Aubrey and a sandstone identified by Dutton as the Shinarump conglomerate. The identification is not convincing, for the only descriptive terms employed are of general application and indicate a character which one cannot suppose to be persistent. The Shinarump conglomerate is referred to by Dutton, in speaking of its general character, as "a well-marked, coarse sandstone," and as "a very coarse conglomeratic sandstone." The only statement of its character in the Zuñi Plateau is in the first three words of the following sentence: "The coarse sandstone, equivalent, I believe, to Powell's Shinarump conglomerate, will be for the present the provisional base of the [Triassic] series" (**8**, p. 135). In view of Ward's statement that conglomeratic beds appear variably through some

eight hundred feet of strata, on the Little Colorado, one may question the correctness of Dutton's identification of this datum horizon. This doubt is strengthened by the statement that for 650 feet above the "conglomerate" the "strongly-colored sandy shales abounding in selenite and silicified wood . . . . resemble so exactly the Permian below that it is quite impossible to distinguish them lithologically" (**8**, p. 135). Between these shales of Permian aspect and the Wingate sandstone which Dutton correlates with the Vermilion Cliff occur eight hundred to nine hundred feet of strata which are rarely so well exposed that their character can be ascertained. They are referred to as "lighter colored, pale, dull-red shales." It seems inherently probable that the base of the Triassic series is in this ill exposed part of the section, not far below the Vermilion Cliff or Wingate sandstone.

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The original sweeping assertions of Powell and Dutton that the Shinarump Group, including all beds between the Aubrey and the Vermilion Cliff, extends, in almost unmodified development, north through the Plateau country to the Uinta Mountains were based on insufficient knowledge. There is much evidence to show that the strata of the section in question do not preserve that wonderful constancy of character, nor the uniform thickness to be inferred from Dutton's words, which have been quoted. This holds true for both Triassic and Paleozoic parts of the section.

Let us first review the knowledge concerning these deposits in the upper reaches of the cañon of the Colorado, and of its branches, the Grand and Green Rivers.

*Vicinity of the Henry Mountains.*—Going up the Colorado less than seventy-five miles above the mouth of Paria River, where Powell, Dutton, Gilbert, and others have examined the section, we come to the area included in Gilbert's study of the Henry Mountains. For that area he has given the following general section of the Shinarump Group (**12**, p. 6).

| | | FEET |
|---|---|---|
| | Top | |
| *a.* | Variegated clay shale; purple and white above and chocolate below, with silicified wood | 300 |
| *b.* | Gray conglomerate, with silicified wood; the Shinarump conglomerate | 30 |
| *c.* | Chocolate-colored shale, in part sandy | 400 |
| | | 730 |

Beneath this section comes the Aubrey sandstone; above it is the Vermilion Cliff sandstone.

This section is materially different from those given by Powell, Walcott, and Ward, but no explanation is offered by Gilbert. He states that evidence of unconformity below the Shinarump conglomerate was not found in the Henry Mountains, but if only four hundred feet of strata there intervenes between the conglomerate and the fossiliferous Aubrey, there is reason to believe that the stratigraphic break at that horizon is considerable.

The constitution of the beds assigned to the Shinarump is certainly different from that of the typical section of the Kanab. There is nothing said of sandstones on the one hand or gypsiferous beds on the other.

*The Lower San Juan Valley.*—In connection with this Henry Mountains section, it is well to consider the observations made by H. S. Gane on the northern side of San Juan River, near the Colorado, which I made public in an earlier discussion of the red beds of the Plateau Province (**4**, p. 476). Gane traced several Mesozoic formations down the San Juan Valley from the head of McElmo Creek in Colorado, a point very near the La Plata quadrangle, where he had assisted in the study and mapping of those formations, under my direction (**2**). Among the formations, the continuity of which to the Colorado Canyon seemed clear to Gane, is the Dolores Triassic formation, at the base of which and recurring irregularly in the lower sandstone is a fine-graided conglomerate consisting largely of limestone pebbles and carrying teeth and fragments of bones of several vertebrates. Tracing this fossiliferous zone down the valley, Gane found in it at Clay Hill divide, about twenty miles east of the northern end of Glen Canyon, a portion of a crocodile jaw, unusually well preserved. This specimen was described by Lucas (**16**) as the type of *Heterodentosuchus ganei*. This form is the most abundant one in the collection made by Ward and Brown in the Leroux beds and it is also very common in the Dolores formation in the San Juan region of Colorado, as appears from the work in my charge. Unios were noted by Gane associated with the vertebrate.

There is no means of proving that the conglomerate called the Shinarump by Gilbert in his section is the same as that carrying

crocodilian remains at Clay Hill, but, from the ensuing discussion, it will seem not at all unlikely that such is the case.

*Newberry's Grand River section.*—Where the Colorado begins, at the junction of Grand and Green Rivers, about forty-five miles northeast of the Henry Mountains, is one of the points cited by Dutton at which the Shinarump Group is typically developed (see p. 103) and where he says the Shinarump conglomerate is found in its characteristic form. Aside from the very general statements of Powell (**22**), I can find nothing in the literature of the Plateau Province recording observations made at this locality. Dutton refers to Newberry's description of the formations on Grand River some miles above the junction with the Green. The vivid pen pictures of the scenery and of the broader stratigraphic features given by this earlier explorer of the region do indeed agree very well with those of Powell, but it is difficult to recognize the Shinarump of Arizona in the section Newberry gives of the possible Triassic beds. He found fossiliferous Carboniferous strata (which Dutton and Powell considered as Aubrey) in the Grand River Canyon where he descended to the stream,[1] and measured the superjacent section of red beds in "Cañon Colorado," the side gorge traversed in making the descent. This section follows (**20**, p. 99):

SECTION IN CAÑON COLORADO, UTAH (NEWBERRY)

| | | FEET |
|---|---|---|
| 9. | Red and brown massive sandstone, fine-grained, not hard. No fossils | 270 |
| 10. | Soft red sandstone, in thin layers, separated by beds of red or dark brown shales . . . . . | 350 |
| 11. | Greenish-gray micaceous conglomerate and gray sandstone, separated by red and purple shales . . . . . | 92 |
| 12. | Soft liver-colored sandstones, becoming suddenly and locally nearly white, with partings of shale . . . . . | 350 |
| 13. | Brick-red massive calcareous sandstones, with some like the last. . | 164 |

As I have explained in the paper on a reconnaissance to Grand River, at Moab (**5**, p. 644), the strata under No. 9 of Newberry's section clearly belong to the lower part of the La Plata or White Cliff

[1] Newberry believed that the side cañon descended by him to Grand River was but a few miles above the union with Green River. But it seems from most recent maps that the "Cañon Colorado," in which Newberry's route lay, enters Grand River cañon about twenty-four miles above Green River, and only about nine miles below the present site of Moab.

Jurassic sandstone, and No. 10 to the Vermilion Cliff sandstone. Possibly No. 11 contains the Shinarump conglomerate. If so, it would appear that the Triassic portion of the Shinarump is represented by but ninty-two feet of beds at this point. On that basis Newberry's section is in close agreement with that a few miles farther up Grand River, next to be considered. But Nos. 12 and 13 are quite unlike the strata underlying the Shinarump conglomerate in Arizona. Fossil wood was not mentioned by Newberry in any of the strata assigned to the Trias. These considerations show that that part of the section on lower Grand River corresponding to the Shinarump in stratigraphic position does not in fact resemble the typical section of that group closely in any particular.

*Grand River Valley near Moab.*—That the generalization just expressed is correct has been amply demonstrated by an examination by myself and associates of the formations exposed in the Grand River Valley near Moab and for about twenty five miles above that point. I have recently published (**5**) the results of that reconnaissance, made in 1905, and need here repeat only the salient facts affecting the question of the Shinarump.

The Vermilion Cliff and White Cliff sandstones, of the general character noted by Powell, are unmistakable datum formations from which to start in stratigraphic studies in Grand River Valley. Below the former, however, we found many things at variance with the idea of simplicity and regularity in this part of the section. Opposite Moab on the northwest side of Grand River the section exposed below the Vermilion Cliff sandstone is as follows:

SECTION NEAR MOAB, UTAH

| | | FEET |
|---|---|---|
| | Top, Vermilion Cliff Sandstone | |
| 12. | Sandstone, massive or shaly, dark red at base and bright red at top | 20 |
| 11. | Shaly, conglomeratic sandstone with numerous reddish limestone pebbles the size of a pea or smaller; a few small bone fragments | 6 |
| 10. | Sandy shales, red and green | 5 |
| 9. | Débris slope apparently representing red shale | 20 |
| 8. | Limestone conglomerate, with a few inches of limestone at top; fossil wood and bone fragments; pebbles less than two inches diameter | 10 |
| 7. | Sandstone, gray, massive | 20 |
| | | 81 |

| | | |
|---|---|---|
| | Carried forward | 81 |
| 6. | Limestone conglomerate, grading into sandstone | 1½ |
| 5. | Sandstone, gray, massive, becoming shaly near top | 23 |
| 4. | Calcareous sandstone with fine-grained conglomerate near base and top; pebbles of limestone and sandstone with occasional bone fragments; pebbles vary from size of a pea to several inches diameter | 9 |
| 3. | Red sandy shale alternating with sandstone | 8 |
| 2. | Conglomerate containing pebbles of limestone and sandstone | 1 |
| 1. | Sandstone and shale alternating, red and green, the shales sandy and friable | 35 |
| | | 158½ |

Beneath No. 1 of this section is a blue limestone carrying coral (Zaphrentis), and, in all, 380 feet of Pennsylvanian beds are exposed, consisting of alternating sandstones and limestones, with abundant fossils. No unconformity was noticeable between the coralline limestone and the overlying sandstone and it is not certain whether Nos. 1, 2, and 3 of the above section should be included with the Carboniferous or not.

The point to be emphasized is that for somewhat more than one hundred feet below the Vermilion Cliff in this section the beds present the characteristics of the lower part of the Dolores formation of Colorado rather than of anything hitherto described from the Shinarump. There is at most only about forty-five feet of beds referable to any formation between the Pennsylvanian and Dolores.

In Grand River Canyon, twelve miles above Moab, the bone-bearing limestone-conglomerate series is found in marked angular unconformity with the underlying beds and it is probable that two thousand feet of strata consisting of two groups of sandstones, conglomerates, and shales, separated by a gypsiferous-shale series, are present between the Pennsylvanian and Dolores strata. No fossils were found in these intermediate beds, but they seem to correspond to the strata of possible Permian age known in Colorado between the Dolores and Hermosa (Pennsylvanian) formations, and collectively termed the Cutler formation in the San Juan folios (**3**).

We found no specifically determinable bones in the beds below the Vermilion Cliff on Grand River. The best obtained was a crushed vertebra belonging, according to Mr. Gidley, to a Triassic form of carnivorous Dinosaur, or possibly to a belodont crocodile. The

fragmentary condition of the remains and the rarity of determinable specimens is, however, entirely analoguous with the occurrence of similar material in the Dolores beds in Colorado.

Poorly preserved Unios are common in the Dolores formation and we observed very similar undeterminable shells in the conglomerate with bone fragments, at Moab. Three species of Triassic Unios in a much better state of preservation were found some years ago on Grand River very near the Vermilion Cliff sandstone by L. M. Prindle (**5**, p. 653), and there is no basis for doubting that they came from the bone-bearing series of beds.

With this knowledge of the Moab and Grand River sections, it seems almost certain that the ninety-two feet of strata embraced under No. 11 of Newberry's section represent the series of bone-bearing conglomerates, etc., which we refer to the Dolores formation. The absence of the gypsiferous shales and of the overlying conglomerates, sandstones, and shales, indicates a stratigraphic break in Newberry's section and the probable horizon of the break is beneath No. 11.

*Uinta Mountains.*—The statements of Powell and Dutton that the Shinarump Group is typically developed on the flanks of the Unita Mountains are without confirmation in the descriptions of the strata referred to the Triassic by these authors or the geologists of the Fortieth Parallel Survey. Powell refers 1,095 feet of beds west of Flaming Gorge to the Shinarump and describes them briefly as follows: "Shales and sandstones containing much gypsum; weathering in many colors, but brown and chocolate tints prevailing; in many places constituting bad-land beds" (**23**, p. 152). There is no suggestion of the Shinarump conglomerate in this section.

It is clear that Powell included in the Shinarump of the Uintas the beds called Permo-Carboniferous by the Fortieth Parallel geologists, and Permian by Dutton in his Grand Canyon monograph, and the description above cited seems to apply to those strata. There is no known evidence that the fossiliferous horizon found at Moab is present on the Uinta slopes, but the discovery reported by Williston (**28**) of a Triassic vertebrate fauna in Wyoming closely related to, if not identical with, that from the Little Colorado Valley and the Dolores formation makes it not improbable that closer study will

disclose the fossiliferous horizon in the Uinta Mountains. From the relations found on Grand River, it seems probable that the equivalent of the "saurian conglomerate" occurs near the Vermilion Cliff sandstone if present at all in the Uinta section.

The only statement I have found in regard to the Trias of the Uintas suggesting the presence of the fossiliferous horizon of the Dolores formation, or, as it might be otherwise interpreted, of the Shinarump conglomerate, is a passage from King's description of the section on the northern slopes of the mountains near Vermilion Creek. He remarks that the basal portion of the Trias consists "of red conglomerate-bearing sandstones which carry a seam of drab limestone. Above these is a body of red sandstone of several hundred feet" (**14**, p. 259). This heavy sandstone seems to correspond to the Vermilion Cliff sandstone, for above it comes a lighter-colored cross-bedded sandstone answering to the White Cliff or La Plata sandstone. Emmons describes the same section in similar terms (**10**, p. 275). Presumably the "conglomerate-bearing sandstone" is quite near the Vermilion Cliff and this at once suggests comparison with the Grand River section.

The foregoing discussion has not taken into account the lower Triassic beds of southeastern Idaho, often termed the "Meekoceras beds" from characteristic marine fossils they contain. These beds are not known in any of the areas referred to in this paper. If ever present in Colorado or the Plateau Province the marine lower Triassic beds must have been removed by the pre-Dolores erosion. The interesting problem as to the relations of the Meekoceras beds to the so-called Permian or Permo-Carboniferous formations of Utah is clearly beyond the scope of this paper.

It is hoped that the foregoing discussion will have made clear to the reader that there are strong reasons for correlating the Triassic portion of Powell's Shinarump Group with the lower part of the Dolores formation of Colorado. The fossiliferous "saurian conglomerate" of the Dolores has been traced into the heart of the Plateau country and a notable unconformity found below it there as well as in the San Juan Mountains of Colorado. The reptilian fauna of the "saurian conglomerate" has been found on the Little Colorado,

at a horizon corresponding closely to that at which the Shinarump conglomerate must come, and at a point only about sixty miles southeast of typical exposures of that conglomerate in the cliffs of the Paria Plateau. On stratigraphic grounds it appears probable that the Shinarump conglomerate and the "saurian conglomerate" occur at the same horizon.

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# A PYRRHOTITIC PERIDOTITE FROM KNOX COUNTY, MAINE[1]—A SULPHIDE ORE OF IGNEOUS ORIGIN

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The rock here described, though of slight areal extent, is of rather unusual interest as a representative of a little-known type of sulphide ores consolidated from a molten magma, and also as the first-described representative of subclass 2 of the perfemane class (class V) of the quantitative system of classification, all of the extremely basic rocks thus far described falling in subclass 1, perfemane, of this class. The rock also shows beautiful examples of reaction rims of hornblende between plagioclase feldspar and olivine, an alteration to which little reference has been made in petrographic literature.

*Location and geologic occurrence.*—The rock here described occurs on the farm of Mr. Charles A. Millers, about three-fourths of a mile southwest of the village of East Union in the town of Union, Knox County, Maine. It constitutes a single outcrop about forty to fifty feet across. The rock disintegrates rapidly, and the partly disintegrated material has been excavated to some extent for use in improving the roads. All of the present surfaces are rusty, and a number of well-rounded bowlders of disintegration which have withstood weathering longer than other portions lie partially imbedded in the gravelly disintegrated material. The rock is extremely tough and resistant under the hammer.

In the woods, about one-half mile southeast of the outcrop described above, a small prospect pit has been dug in loose ferruginous material, which probably passes below into rock similar to that on the Millers farm.

The above-mentioned localities lie within the area of the Rockland quadrangle, near its western border. The rocks of the region are regionally metamorphosed sediments probably of Cambro-Ordovician age, which have been intruded and further metamorphosed by granitic rocks. The peridotite here described is in all probability intrusive

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into these sediments. Gabbroid and dioritic rocks whose relations show them to be differentiation products from the granitic magmas are of common occurrence in this region, and the pyrrhotitic peridotite under discussion probably represents an extreme phase of this differentiation process, although it may on the other hand be wholly unconnected in origin with the granitic intrusions.

MEGASCOPIC APPEARANCE

The megascopic appearance of this rock is so unusual as to attract immediate attention in the field. It is medium-grained (millimeter-

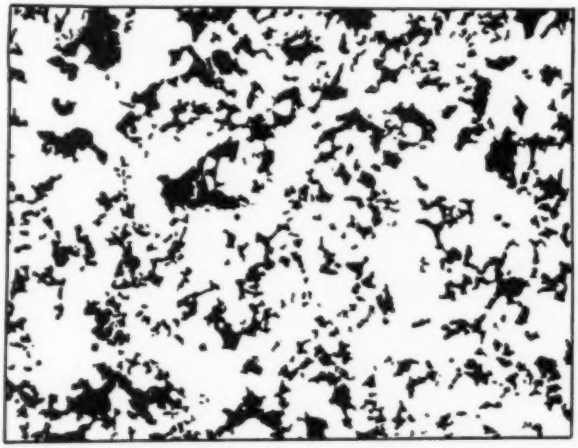

FIG. 1.—Tracing from polished surface of peridotite. The black areas represent pyrrhotite with small associated amounts of chalcopyrite and pyrite. The white areas are occupied mainly by olivine with some hornblende and plagioclase feldspar. (Natural size.)

grained), holocrystalline, and equigranular, and is composed of a yellowish-gray, metallic-looking mineral, which proves to be pyrrhotite scattered in very irregular masses through a ground-mass which for the most part appears structureless and is dark green to nearly black in color. The form and natural size of the pyrrhotite areas are shown in Fig. 1, which was traced from a polished surface.

In irregular association with the pyrrhotite are small amounts of chalcopyrite distinguishable by its yellower tint. Most of the nearly black matrix between the sulphide masses exhibits no trace

of cleavage and is shown under the microscope to be olivine, its dark color being due to the abundance of minute magnetite inclusions which it contains. Scattered dark-green or bronze-colored grains in the ground-mass which show distinct cleavage faces are seen under the microscope to be hornblende. Small, scattered areas, gray in color with a dull luster, are plagioclase feldspar. In general the rock is remarkably fresh. Serpentine and chlorite, which have resulted from olivine and hornblende decomposition, are confined largely to certain layers which are thread-like in form as seen in cross-section on a polished surface. These areas of decomposition are largest between closely grouped pyrrhotite masses, and the narrower strands run from one pyrrhotite mass to another and are parallel in their general trend throughout the hand specimen.

The characters and relationships of the various original and secondary minerals which compose the rock are described in detail below.

### ORIGINAL MINERALS

*Olivine.*—This is the most abundant original constituent of the rock, and estimates on six slides show that it makes up about 60 per cent. by volume of the whole rock. Since the specific gravity of the rock is about 3.42 while the average for olivine is in the neighborhood of 3.35, the percentage of olivine by weight would be only slightly less than this figure. The norm shows only 30.99 per cent. by weight of olivine but in addition shows 22.06 per cent. by weight of hypersthene, a mineral not observed in the rock itself. A part of the iron belonging to the hypersthene in the norm appears in the mode in the more siliceous mineral hornblende, while the remainder appears in olivine, a mineral less siliceous than hypersthene.

The olivine occurs in rounded grains ranging from 1 or $2^{mm}$ to $8^{mm}$ in length, the majority being between 3 and 4 $^{mm}$. Most of the grains are entirely fresh except for a narrow alteration zone of fibrous serpentine about their borders. Certain narrow bands traversing the rock in a manner already described are characterized, however, by much more extensive alteration, and in these areas the olivine grains may be partly or wholly serpentinized, the alteration having, as is usual, been most extensive along the irregular cracks

and about the peripheries of the grains. The characteristic appearance of the less altered olivine grains is shown in Fig. 2, in which most of the narrow serpentine borders appear white. The large black area is pyrrhotite.

*Pyrrhotite.*—Next to olivine, pyrrhotite is the most important mineral of the rock. The analysis shows that it contains small

FIG. 2.—Pyrrhotite (black) in characteristic allotriomorphic association with olivine. The dark bands traversing the olivine are lines of magnetite inclusions. The white borders around some of the olivine grains are serpentine. (Magnification about thirty diameters, polarized light.)

amounts of nickel and cobalt, and constitutes 22.50 per cent. by weight of the whole rock. A small amount of pyrite is also included in this determination and under the microscope this mineral is seen to form a small part of some of the areas between the olivine grains, which are occupied mainly by pyrrhotite. The volume relations between the pyrrhotite (with small amounts of other sulphides) and the other rock constituents may be judged from Fig. 1.

As shown in Fig 2, the pyrrhotite is normally completely allotriomorphic with respect to olivine grains, its relations in this respect being similar in every way to those exhibited by the feldspar. The pyrrhotite is also in contact with fresh massive hornblende and with almost unaltered plagioclase feldspar. The allotriomorphic relation of nearly all the pyrrhotite to unaltered grains of the original mineral olivine is considered to be conclusive evidence that practically all the pyrrhotite is an original crystallization from the magma and is essentially contemporaneous with the other principal constituents of the rock. In a few narrow zones traversing the rock, pyrrhotite occurs in angular areas more or less connected with each other and associated with chlorite and hornblende. These very limited portions may be a secondary crystallization.

*Feldspar.*—In the hand specimens this mineral forms dull-gray areas with irregular outlines, never over one-fourth of an inch and seldom over one-eighth of an inch across. Under the microscope it is found to occupy irregular areas between the rounded olivine grains, with respect to which the feldspar is entirely allotriomorphic. It shows albite and occasionally carlsbad twinning, the angles of the former running up to thirty degrees. The index of refraction as determined on powdered material by the immersion method approximates 1.55. The angle in the section perpendicular to the negative bisectrix between M and the plane of the optic axes is twenty-nine degrees. These results show that the feldspar is andesine-labradorite with approximately the composition $Ab_1An_1$. These are also the exact proportions in which albite and anorthite are present in the norm as calculated from the analysis.

With the exception of the reaction rims of amphibole described in the section on secondary minerals, the feldspar is in general very fresh though some of it is clouded with aggregates of small, highly refracting plates and flakes. Most of these have indices of refraction which are only slightly greater than that of the feldspar, and are probably muscovite. Others of higher index are probably an amphibole similar to that developed between the feldspar and the olivine.

*Hornblende.*—The mineral next in importance is hornblende, which, in some parts of the rock, is almost wholly absent, but in other parts is present in large crystals, which are allotriomorphic with

respect to the olivine grains. Nearly all of the larger hornblende crystals contain small, rounded olivine inclusions, usually fresh, though sometimes serpentinized. The mineral is identified as hornblende by the rhombic cleavage exhibited in some sections, by its index of refraction, which is intermediate between those of olivine and serpentine, and by its double refraction, which, by comparison of its interference colors with those exhibited by olivine, is found to be about 0.022 to 0.024. Its extinction angles in sections in which the cleavage parallel to *c* is well defined range up to twenty-seven degrees. The pleochroism is usually weak though strong in certain sections. The colors vary from pale pink to pale green and, in some sections, deep brown. There is frequently more or less mottling, due to slight variations in color and birefringence from point to point. The contacts between hornblende and olivine and between hornblende and pyrrhotite are in most cases perfectly sharp, neither mineral having undergone alteration. Between hornblende and feldspar, the contact though normally sharp, occasionally shows evidence of some recrystallization of the hornblende next the feldspar. The abundant small olivine inclusions present in the larger hornblendes seem to indicate that the latter mineral followed very close upon the olivine in crystallization and was probably in part contemporaneous with it. The pyrrhotite and feldspar probably crystallized at about the same time, and followed close upon the hornblende crystallization.

*Magnetite.*—Magnetite is present only in minute irregular grains scattered through the olivine crystals in bands of varying width, many of which represent fracture planes. The magnetite as seen in the thin sections seems to form from 5 to 40 per cent. by volume of the olivine grains. The average is estimated at at least 10 per cent. by volume or about 17 per cent. by weight. Since the olivine was estimated to constitute about 60 per cent. by weight of the whole rock the magnetite included in it will form 17 per cent. of 60 per cent. or about 10 per cent. by weight of the whole rock. In the analysis all the iron was determined as FeO but in the calculation of the norm a part was apportioned to 10 per cent. of magnetite, the remaining iron forming 5.64 per cent. of FeO. Many of the magnetite bands extend from one olivine grain into another which is in contact with

it, but they are nowhere observed to continue into adjacent areas of feldspar, hornblende, or pyrrhotite.

*Chalcopyrite.*—The analysis shows this mineral to constitute 1.03 per cent. by weight of the rock. In the hand specimens and slides it is seen to be associated irregularly and in small amounts, as was pyrite, with the areas of pyrrhotite.

*Pyrite.*—Small amounts of pyrite are associated irregularly with the pyrrhotite.

*Biotite.*—This mineral occurs as a few scattered plates seldom over $0.7^{mm}$ in greatest dimension, which in some sections are entirely surrounded by olivine. In other cases the biotite occurs in long narrow areas between olivine and pyrrhotite. In one case, which is shown in Fig. 2, a narrow biotite blade lies at right angles to the contact between perfectly fresh olivine and pyrrhotite, penetrating some distance into each of the crystals. In this occurrence at least it is undoubtedly primary, though some of the plates may be of secondary origin.

*Spinel.*—A few grains of a dark green isotropic mineral occur in certain portions of the rock in irregular association with pyrrotite and hornblende or as inclusions in the latter mineral. Its grains are without regularity in form and range in size up to $0.4^{mm}$ though mostly under $0.2^{mm}$. The mineral is probably pleonaste or chlorospinel.

### SECONDARY MINERALS

*Serpentine.*—This mineral is developed in short, closely aggregated fibers as an alteration product of olivine. Most of it is colorless in the thin section; but rarely light to deep yellow colors occur. Between crossed nicols it is, in some cases, nearly isotropic, while in other cases showing blue-gray interference colors. The serpentinization begins in the normal manner at the borders of the olivine grains and proceeds inwards along irregular cracks. The degree of serpentinization varies greatly in different portions of the rock, some olivine grains showing only a narrow border of serpentine not exceeding $0.015^{mm}$ in width along their contact with pyrrhotite and chalcopyrite, while in other cases the olivine grains have been almost entirely serpentinized.

*Amphibole.*—In addition to original hornblende, whose occurrence has already been described, amphibole occurs as reaction rims between

plagioclase feldspar and olivine or pyrrhotite. Most of these zones vary in width from 0.02$^{mm}$ to 1$^{mm}$, and show a more or less radiate structure, amphibole fibers or brushes being directed about at right angles to the borders of the feldspar crystals. The mineral forming the rims is identified as amphibole by the fact that it is in some places in crystallographic continuity with the massive hornblende already

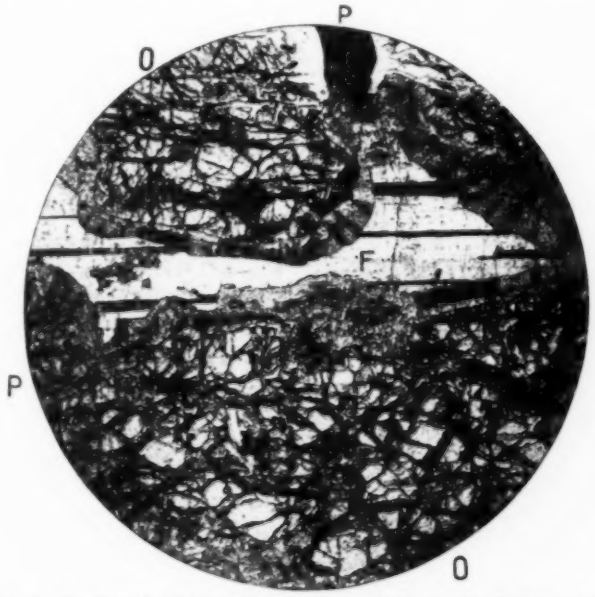


FIG. 3.—Reaction rims of amphibole bordering feldspar. *F* = Feldspar (andesite-labradorite), *P* = Pyrrhotite, *O* = Olivine. Note the double character of the rims between feldspar and olivine, their single character between feldspar and pyrrhotite, and their entire absence between olivine and pyrrhotite. (Magnification about thirty diameters, polarized light.)

described, by its double refraction (about 0.024), and its index of refraction, which is intermediate between those of olivine and serpentine.

Some of these fringe-like borders show two layers of fibers, usually in close contact with each other, but in some cases separated by a narrow band of a non-fibrous hornblende, which usually shows a faint tint of brown. In the double borders developed between

plagioclase and olivine, the bands of minute magnetite inclusions so characteristic of the latter frequently continue through the amphibole band nearest the olivine, but are not present in the band nearest the feldspar, a relation which indicates that both these minerals have been involved in the replacement. The layer nearest the olivine is usually nearly colorless while that nearest the feldspar usually shows a pale-greenish tint. Usually, though not invariably, the rim next the olivine is narrower than that bordering the feldspar. Between feldspar and pyrrhotite only a single reaction rim is developed; it frequently is pale brown in color especially near the pyrrhotite.

The general appearance of the reaction rims is shown in Fig. 3. In the more altered portions of the rock, the reaction zones become somewhat broader and in some cases lose their fibrous character probably as a result of recrystallization. Secondary hornblende of this type in some places grades with perfect continuity into original hornblende. Larger crystals of hornblende associated with chlorite and angular areas of pyrrhotite in certain narrow zones traversing the rock are probably of secondary origin. The hornblende of the reaction rims occasionally grades into hornblende of this type.

In seeking to determine what original minerals were the source, partial or complete, of the hornblende of the reaction rims, it is evident that the best results are likely to be obtained from a study of the freshest portions of the rock, where the alterations are in their initial stages. In these parts of the rock hornblende is uniformly absent between the olivine and the pyrrhotite, serpentine being the secondary mineral developed along these contacts. Between the feldspar and olivine and between feldspar and pyrrhotite, however, a reaction rim of hornblende is always present. The darker color exhibited by the hornblende formed along the feldspar-pyrrhotite contact presumably indicates that the mineral here is richer in iron and proportionately poorer in magnesia than that developed next to the olivine. These relations clearly indicate that the hornblende is developed as a result of chemical interchange between plagioclase and the femic minerals, olivine or pyrrhotite.

It is hardly possible, however, to regard this change as taking place without accession of material from outside or loss to other parts of the rock. This follows from a consideration of the chemical

composition of the original minerals involved. The feldspar of the rock, andesine-labradorite, has the composition $Na_2O \cdot 2CaO \cdot 3Al_2O_3 \cdot 10SiO_2$ and the olivine $2(MgFe)O \cdot SiO_2$. In the former the molecular proportion of soda to lime is as 1:2. In any reaction in which andesine-labradorite and olivine were involved without outside gain or loss, the resulting product should show a similar proportion between $Na_2O$ and $CaO$. As shown by the microscopic studies, the resulting mineral is hornblende, but an examination of the available hornblende analyses shows that in nearly every case the soda is greatly subordinate to the lime, the molecular proportions ranging from soda 1 and lime 12 to soda 1 and lime 3, but in no case approaching the proportion of 1:2. The reaction probably involved, therefore, either a loss of soda, or a notable addition of lime, or both. In the more altered portions of the rock the hornblende, as already stated, occurs in larger, massive crystals which occur not alone between feldspar and the femic minerals but in contact with other constituents. In some places areas originally occupied by plagioclase now show only a few feldspar remnants entirely surrounded by hornblende.

Alterations of the type just described are probably of somewhat common occurrence among peridotites though readily traceable only in rocks which show the initial stages of alteration. Few instances are described in the literature. Van Hise[1] makes the following statement in regard to a reaction between olivine and anorthite:

> In some instances the alteration into actinolite is described as taking place in connection with feldspar as a reaction rim. In this case the calcium may be supposed to be derived from anorthite, as calcium silicate. The aluminum may be supposed to pass into common spinel and hercynite (isometric; sp. gr. 3.93), which are well known to be alteration products of olivine. The reaction may be

$$\underbrace{4Mg_3FeSi_2O_8}_{\text{Olivine}} + \underbrace{4Ca\,Al_2Si_2O_8}_{\text{Anorthite}} = \underbrace{Mg_9Fe_3Ca_4Si_{16}O_{48}}_{\text{Actinolite}} + \underbrace{3MgAl_2O_4}_{\text{Common spinel}} + \underbrace{FeAl_2O_4}_{\text{Hercynite}}.$$

Törnebohm in a description of some of the diabases and gabbros of Sweden describes an alteration to hornblende almost identical with that observed in the Maine rock.

> The alteration of the olivine, as usually exhibited in the rocks under discussion, proceeds exclusively from the borders of the grains. There forms next to it a

[1] C. R. Van Hise, *Treatise on Metamorphism*, Mon. XLVII, U. S. Geological Survey, pp. 310, 311.

colorless zone showing a radial structure, and, especially where the olivine is in contact with plagioclase, there is present always a second more or less regular zone with similar structure. The latter is made up of an aggregate of green, rather highly dichroic grains, all of which are hornblende. It seems as if these zones were developed in consequence of a reaction between the plagioclase and the olivine, the inner zone being formed at the cost of the latter, and the outer zone at the cost of the former. The reaction zone is of particularly constant occurrence between olivine and plagioclase, but between olivine and augite it is absent and if augite penetrates in wedge-like form between olivine and plagioclase then the two zones separate, the green remaining between the augite and the plagioclase and the lighter zone between the olivine and the plagioclase, though both soon wedge out. Neither by heating nor by acids were the zones notably affected. In the much weathered portions of the rock the olivine inside the bright zone is more or less completely altered to a dirty-green mass of serpentine."[1]

THE FOLLOWING ANALYSIS OF THE ROCK IS BY DR. W. F. HILLEBRAND[2]

| | | | |
|---|---|---|---|
| $SiO_2$ | 28.04 | $TiO_2$ | .20 |
| $Al_2O_3$ | 3.51 | $P_2O_5$ | .04 |
| $Fe_2O_3$, FeO | 14.95[3] | MnO | .24 |
| | | SrO | trace? |
| MgO | 21.97 | $CO_2$ | 1.01 |
| CaO | 1.78 | $Fe_7S_8$ | 21.53[4] |
| $Na_2O$ | .28 | NiS | .94[5] |
| $K_2O$ | .08 | CoS | .03[5] |
| $H_2O+$ | 2.54 | $CuFeS_2$ | 1.03 |
| $H_2O-$ | 1.48 | Total | 99.65 |

*Chlorite and calcite.*—These minerals occur only in the more weathered portions of the rock in association with massive secondary hornblende and recrystallized (?) pyrrhotite. The chlorite belongs to the chlinocore variety and is mostly light green in color though a

[1] A. E. Törnebohm, "Ueber die wichtigeren Diabas und Gabbro-Gesteine Schwedens," *Neues Jahrbuch für Mineralogie*, 1877, pp. 382, 383. Translation by E. S. B.

[2] Laboratory of U. S. Geological Survey.

One hundred grams of pyrrhotite were tested for platinum, but none was found.

[3] The iron was calculated as FeO. Some is present as $Fe_3O_4$, which would raise the summation. The figure for the oxides of iron is only approximate because of the impossibility of calculating the amount of pyrite or the exact composition of the other sulphides.

[4] Includes some pyrite.

[5] Occurs combined with or closely associated with pyrrhotite.

The olivine grains contain so much magnetite in the form of inclusions that they adhere strongly to a magnet. From microscopic examination it was estimated that the magnetite formed about 17 per cent. by weight of the olivine or approximately 10 per cent. by weight of the whole rock. The iron belonging to the 14.95 per cent. of FeO in the analysis (11.63 per cent. of Fe) was redistributed on the basis of 10 per cent. of $Fe_3O_4$, the total of the rock constituents thus being raised to 100.34 per cent.

few of the larger and more massive grains are a deep grass green. The interference colors between crossed nicols vary from greenish yellow and dark gray in the light-green portions to very dark gray in the deep green. The mineral is, in part at least, the product of hornblende decomposition. Calcite occurs in small, irregular crystals and in aggregates of minute grains associated with chlorite, and also as a few larger grains associated mainly with secondary hornblende.

CALCULATION OF THE NORM FROM THE ANALYSIS

| | Percentage Weights | Mol. Proportions | Cal. | Or. | Ab. | An. | Cor. | Rut. | Hy. | Ol. |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 28.04 | 467 | | 6 | 24 | 16 | | | 212 | 209 |
| $Al_2O_3$ | 3.51 | 34 | | 1 | 4 | 8 | 21 | | | |
| $Fe_3O_4$ | 10.00 | | | | | | | | | |
| FeO | 5.64 | 81 | | | | | | | 27 | 54 |
| MnO | .24 | | | | | | | | | |
| MgO | 21.97 | 549 | | | | | | | 185 | 364 |
| CaO | 1.78 | 31 | 23 | | | 8 | | | | |
| $Na_2O$ | .28 | 4 | | | 4 | | | | | |
| $K_2O$ | .08 | 1 | | 1 | | | | | | |
| $H_2O$ | 4.02 | | | | | | | | | |
| $TiO_2$ | .20 | 3 | | | | | | 3 | | |
| $P_2O_5$ | .04 | | | | | | | | | |
| $CO_2$ | 1.01 | 23 | 23 | | | | | | | |
| $Fe_2S_3$ | 21.53 | | | | | | | | | |
| NiS | .94 | | | | | | | | | |
| CoS | .03 | | | | | | | | | |
| $CuFeS_2$ | 1.03 | | | | | | | | | |
| Total | 100.34 | | 23 | 1 | 4 | 8 | 21 | 3 | 212 | 209 |

| | | |
|---|---|---|
| Orthoclase | .56 | Salic 7.02 |
| Albite | 2.10 | |
| Anorthite | 2.22 | |
| Corundum | 2.14 | |
| Rutile | .20 | Femic 86.78 |
| Hypersthene ($FeO \cdot SiO_2 = 3.56$; $MgO \cdot SiO_2 = 18.50$) | 22.60 | |
| Olivine ($2\,FeO \cdot SiO_2 = 5.51$; $2\,MgO \cdot SiO_2 = 25.48$) | 30.99 | |
| Nickel- and cobalt-bearing Pyrrhotite | 22.50 | |
| Magnetite | 10.00 | |
| Chalcopyrite | 1.03 | |
| Water | 4.02 | |
| Calcite | 2.30 | |
| $P_2O_5$ | .04 | |
| | 100.16 | |

| | | |
|---|---|---|
| Class | $\frac{\text{Sal.}}{\text{Fem.}} = \frac{7.02}{86.78} = <\frac{1}{7}$ | = V, perfemane. |
| Subclass | $\frac{\text{POM}}{\text{A}} = \frac{63.25}{23.53} = <\frac{7}{1}>\frac{3}{1}$ | = 2, dofemone. |
| Order | $\frac{\text{PO}}{\text{M}} = \frac{53.05}{10.00} = <\frac{7}{1}>\frac{3}{1}$ | = 2, dopolic, Mainare. |
| Section | $\frac{\text{P}}{\text{O}} = \frac{22.06}{30.99} = <\frac{1}{2}>\frac{2}{1}$ | = 3, pyrolic, Mainiare. |
| Rang | $\frac{(\text{MgFe})\text{O}+\text{CaO}}{\text{K}_2\text{O}+\text{Na}_2\text{O}} = \frac{29.63}{.36} = >\frac{7}{1}$ | = 1, permirlic. |
| Section | $\frac{(\text{MgFe})\text{O}}{\text{CaO}} = \frac{27.85}{1.78} = >\frac{7}{1}$ | = 1, permiric. |
| Subrang | $\frac{\text{MgO}}{\text{FeO}} = \frac{21.07}{5.88} = <\frac{7}{1}>\frac{3}{1}$ | = 2, domagnesic, Lermondose |

Since the rock shows a slight amount of alteration the norm computed above can be regarded only as approximating that of the fresh rock. The rock, however, falls well within the limits of each of the divisions in the above classification, and it is not probable that the weathering has produced changes sufficient to change its position in the quantitative classification.

The name Lermondose which is here proposed for the rock is derived from Lermond Pond, situated about one mile northeast of its type exposure. The ordinal name Mainare is a reference to the state of Maine, in which the rock occurs.

*Bearing on the origin of certain sulphide ores.*—Chalcopyrite is present in such small amounts and the percentages of nickel and cobalt associated with the pyrrhotite are so small that the rock has no present economic value as an ore. The sulphides are also associated in such an intimate way with the other rock minerals as to make their complete separation difficult. The rock, nevertheless, exhibits an unusual concentration of metallic sulphides common in many ore deposits, and from a theoretical standpoint at least may be regarded as an example of ore formed by original crystallization from the molten magma. It seems but a short step from a rock of this type to one in which chalcopyrite is present in sufficient amounts or in which the percentage of nickel or cobalt in the pyrrhotite is large enough to give the ore commercial value. The existence of commercial deposits of sulphide ores of such purely igneous origin has, so far as known to the writer, never been satisfactorily demon-

strated, but the possibility of their existence can hardly be questioned in view of the known occurrence of igneous rocks as rich in sulphides as the one here described. That this rock is itself a differentiation from a less basic magma is shown by the occurrence about one-quarter mile northeast of the Millers farm of a much less basic rock belonging apparently to the same intrusion but containing relatively small amounts of pyrrhotite. The original characters of this rock are obscured by intense weathering, which has reduced the rock to an irregular aggregate of pale-green chlorite, pale-green or brown amphibole, much of it fibrous, and calcite.

Sulphide-bearing rocks of the type here described are, however, even more suggestive in their bearing on workable ore deposits when we take into account the possibilities of local sulphide enrichment by aqueous or pneumatolytic action. There is no evidence of such enrichment at the locality near East Union, nor do the rocks of the surrounding region contain ore veins of any kind. It is evident, however, that such processes acting upon a rock of this type would be fully capable of producing ore deposists of a commercial character.

Adams,[1] Coleman,[2] and Barlow[3] of the Canadian Geological Survey have all attributed the primary concentration in the copper, nickel, and cobalt ores of the Sudbury district of Ontario to magmatic differentiation in a magma which normally crystallized as a norite or gabbro, while admitting the importance in this region of secondary concentration by aqueous agencies. Vogt has expressed similar views of the genesis of the sulphide ores of the Scandinavian nickel deposits. On the other hand Posepny[4] has affirmed that the original crystallization of pyrrhotite in any notable quantities is a chemical impossibility, and the views of Adams, Coleman, and Barlow have been challenged by a number of writers partly on theoretical and partly on observational grounds.

While affirming nothing in regard to the origin of the ore deposits

[1] F. D. Adams, *Canadian Mining Bureau*, January, 1894, p. 8.

[2] A. P. Coleman, *Bureau of Mines Report*, Ontario, 1905, Part III, and this JOURNAL, Vol. XV, pp. 759–82, 1907.

[3] A. E. Barlow, *Summary Report of the Director of the Geological Survey of Canada*, 1901.

[4] "The Genesis of Ore Deposits," *Transactions of American Institute of Mining Engineers*, 1893.

of either of these regions, the writer believes that such occurrences, as that near East Union demonstrate beyond question that pyrrhotite, in very considerable percentages, may occur as an original crystallization from igneous magmas, and the possibility of at least a primary concentration of this sort must be recognized in the study of the origin of sulphide ores, particularly those of nickel and cobalt.

# THE COTYLOSAURIA

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The studies of Broili, and especially of Case, have furnished much welcome information concerning the Permian reptiles of America within recent years. But our knowledge of many of them is yet meager, and much obscurity yet prevails as to their rank and affinities, and especially as to their relationships with the known European and African types. The ordinal name Cotylosauria has, within the past few years, come into rather general use for many of the early stegocrotaphous reptiles to the exclusion of other terms which had previously been applied to them. A brief historical review of the origin and use of the term will be of interest.

Cope early introduced and made use of the term Theromorpha, afterward changed to Theromera, to include many of the older reptiles now recognized as quite diverse, and which he later so recognized, abandoning it. In 1880[1] he proposed the subordinal term Cotylosauria for a division of this group, founded exclusively on the Diadectidae of Texas, and based upon a real or apparent dicondylar structure of the skull. Later,[2] he expressed doubt of its validity as follows:

> I am still inclined to question whether the extraordinary characters of the cranio-vertebral articulation I have described justify the separation of the Diadectidae as a third suborder of the Theromorpha, which I have called the Cotylosauria, or whether they are not due to the loss of a loosely articulated basioccipital bone.

The two other suborders of his Theromorpha to which he refers were the Pelycosauria and Anomodontia—this latter of course in its wide sense. In 1889[3] he included in his order Theromera the following six suborders: Placodontia, Proganosauria, Parasuchia, Anomodontia, Pelycosauria and Cotylosauria. His Pelycosauria included

[1] *American Naturalist*, p. 334.

[2] *Proceedings of the American Philosophical Society*, 1882, p. 448.

[3] *American Naturalist*, p. 886.

the families Clepsydropidae, Pariotichidae and Bolosauridae; his Cotylosauria, the Diadectidae and Pareiasauridae; the Proganosauria, the Mesosauridae, Procolophonidae, Paleohateriidae, Proterosauridae, and Rhynchosauridae (equivalent, it is seen, plus the Rhynchocephalia and Choristodera, to Osborn's Diaptosauria). In 1891,[1] Cope defined the Cotylosauria, now for the first time considered an order, as including four families, the Diadectidae, Pareiasauridae, Pariotichidae, and Elginiidae. In the later publication he erected the order Chelydosauria for the Otocoelidae proposed a few years before for certain new reptiles from Texas, defining it as having the scapular arch internal to the ribs, a dermal carapace, and the temporal roof excavated posteriorly for the auricular meatus. Until this time *Pariotichus* had been included among the Pelycosauria. In 1896,[2] however, he referred one species described as *Pariotichus*, *P. hamatus*, to a distinct genus, *Labidosaurus*, which he provisionally placed among the Pareiasauridae.

In a few words, it is seen that Cope based the suborder Cotylosauria upon the Diadectidae, and not until his later papers did he unite any other American forms with it in the same group. In 1905,[3] Case brought evidence to show that the essential characters assigned to the Chelydosauria were also common to *Diadectes* and its allies, and he has withdrawn the family from the Cotylosauria to include it, with the Otocoelidae, in the Chelydosauria, leaving *Pariotichus* and certain other less well-known forms as the sole American representatives of the Cotylosauria. But this contravenes the basal rules of nomenclature. The group originally was based exclusively upon the Diadectidae, and, while we may add as many other families as we choose, we may not substract the one upon which it was alone based. The name Cotylosauria, of which Chelydosauria is purely a synonym, must accompany the Diadectidae wherever the family is placed.

With the elimination of Chelydosauria we have three ordinal terms which have been proposed for the primitive stegocrotaphous reptiles: Cotylosauria Cope (suborder, 1880, order 1891); Pareia-

[1] *Amer. Naturalist*, p. 644; *Syllabus of Lectures on the Vertebrates*, p. 68.

[2] *Proceedings of the American Philosophical Society*, p. 136.

[3] *Journal of Geology*, No. 2, 1905. p. 126.

sauria Seeley (1892);[1] and Procolophonia Seeley (1889).[2] The question of immediate interest is, in which of these two latter groups, if either, can *Pariotichus* and the other forms eliminated by Case from the Cotylosauria be placed. Its interest has led me to re-examine in the light of the recently accumulated facts concerning the older reptiles, the excellent specimen in the Chicago University collections described by Case some years ago[3] as *Pariotichus incisivus* Cope. For the general description of the specimen the reader is referred to the cited paper. By further preparation of the specimen I am able to make some additions of interest.

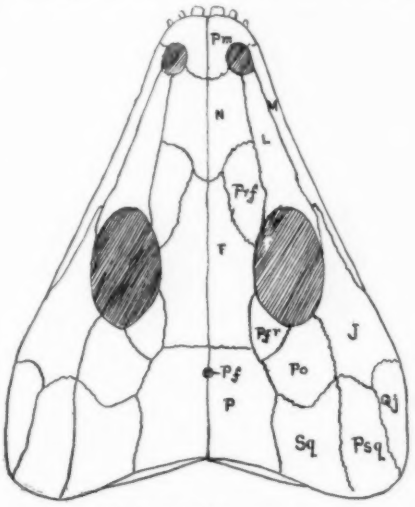


FIG. 1.—Skull of *Labidosaurus incisivus*, upper surface; one-half natural size. *Pm*, premaxilla; *N*, nasal; *M*, maxilla; *L*, lachrymal; *F*, frontal; *Prf*, prefrontal; *Pof*, postfrontal; *Po*, postorbital; *J*, jugal; *Pf*, parietal foramen; *P*, parietal; *Sq*, squamosal; *Psq*, prosquamosal; *Qj*, quadratojugal.

My determination of the upper elements of the skull (Fig. 1) made independently, agrees well with Case's. On the under surface, however (Fig. 2), I am quite unable to differentiate the pterygoids, palatines, and vomers anteriorly, they are so closely fused together. I do not feel at all sure about the distinction of the parocci-pital as a separate element. The epiotics may be present, but I am not sure.

Eighteen presacral vertebrae were collected by Professor Case with the specimen, and he was inclined to the belief that this was the full number. Four of these, without rib attachments, are connected

[1] *Philosophical Transactions*, 1892, p. 106.

[2] *Ibid.*, 1889, p. 270.

[3] *Zoölogical Bulletin*, Vol. II, 1899, p. 231

yet with the sacrum and pelvis. Six are united in a series lying over the pectoral girdle, with ribs or portions of ribs attached. In addition, there are two united pairs, and two single vertebrae. Between the two series there are quite evidently several missing, since the diapophyses end abruptly with the pectoral series. From the size and shape it seems apparent that the two pairs belong here, making at least fourteen dorsals. Both of the single vertebrae have small rib diapophyses; they are also smaller in size. I have placed them in the neck in the restoration (Fig. 6). However, *Labidosaurus hamatus* has, according to Broili,[1] at least twenty-two presacral vertebrae; and *Telerpeton*, according to Boulenger,[2] twenty. It is probable, hence, that two or more vertebrae have been lost in the present specimen from in front of the sacrum. The neck could not have been longer than is represented in the restoration, perhaps not so long, since so broad and ungainly a head would have been sadly unmanageable on a slender neck. At least four presacral vertebrae bore no ribs, but I believe

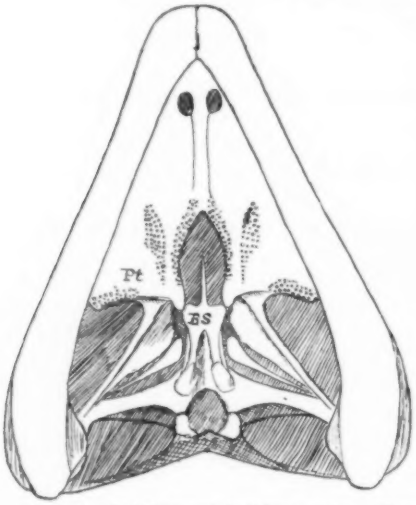


FIG. 2.—*Labidosaurus incisivus*, under surface of skull; one-half natural size. *Pt*, pterygoid; *Bs*, basisphenoid.

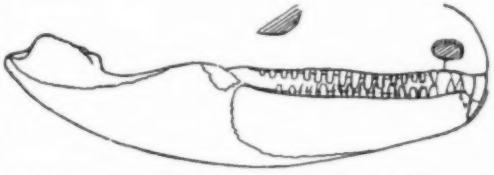

FIG. 3.—Mandible and maxillary teeth of *Labidosaurus incisivus*, one-half natural size.

[1] *Paleontographica*, 1904.

[2] *Proceedings of the Zoölogical Society*, London, 1904, p. 474.

that all the others, save perhaps the atlas, had such bones. Three caudal vertebrae are preserved together, in addition to two connected with the sacrum. They evidently bore ribs and indicate a short tail.

The pectoral girdle I am able to restore completely with assurance. The sutures between the scapula and the coracoid elements I find to be as represented in the drawing, with the exception of that between the scapula and the procoracoid anteriorly, of which I am in doubt, because of the absence of that part of the arch on the left side with

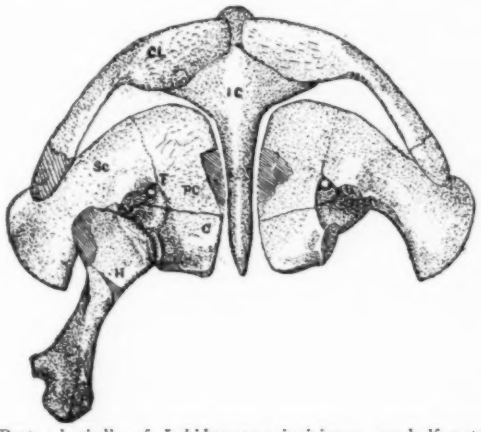


FIG. 4.—Pectoral girdle of *Labidosaurus incisivus;* one-half natural size. *I*, interclavicle; *Cl*, clavicle; *Sc*, scapula; *C*, coracoid; *Pc*, procoracoid; *F*, coracoid foramen.

its corroboratory evidence. There is a small but distinct, coracoid foramen between the procoracoid and the scapula. There is, as Case has said, no evidence of a cleithrum, nor is there any place where one could have been attached. The scapular surface of the distal extremity of the clavicle, of which the tip only is wanting, is striated, and the scapula presents a similar surface for its attachment in the position shown in the drawing. The diagrammatic position in which it is necessary to figure the arch distorts somewhat the relations of scapulae and clavicles. The distal extremity of the scapula was evidently turned dorsad at nearly a right angle with the plane of the

coracoid surface. The proximal end of the right humerus lies perfectly in position in the glenoid fossa. The distal extremity of the bone, twisted in a plane nearly at right angles with that of the proximal, presents not the slightest indication of an entepicondylar foramen, and the bone is not at all mutilated. The absence of this foramen is, however, extraordinary, since very nearly all the known reptilian vertebrates of the Permian have it, though not all, according to Cope. The thinned margin of the proximal expansion has been lost in the specimen. There is the possibility, a remote one I believe in view of the fact that the relations of the various bones of the skeleton had suffered little disturbance, that the humerus had been completely and perfectly reversed in the glenoid socket, and some indication of this reversion is furnished in that the so-called distal end agrees fairly well with the proximal end of some forms.

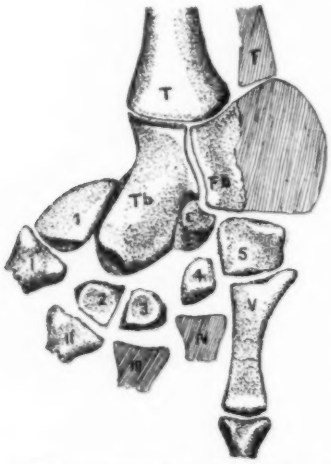


FIG. 5.—Hind foot of *Labidosaurus incisivus;* natural size. *T*, tibia; *F*, fibula; *Tb*, tibiale; *Fb*, fibulare; *C*, centrale; 1–5, distal tarsals; I–V, metatarsals.

In the structure of the feet I have no emendations to make of Professor Case's interpretations, save of the centrale of the pes. This bone I find, on removal of the bone lying over it, to be pretty well fused with the tibiale, the union shown, however, clearly in a sutural line. Broom has expressed a doubt of the structure of the feet in this specimen. There can be none. The number and arrangement of the bones of the carpus are assuredly as Case has figured them. As to the number of the phalanges in the digits I believe that they will be found to be as in *Procolophon* and *Telerpeton*, 2, 3, 4, 5, 3, or 4. The pelvic girdle in this specimen is typically that of the old reptiles, elongated, flat, plate-like pubes and ischia, closely united by suture and wholly without a thyroid foramen. It is the pelvis of *Procolophon*, *Telerpeton*, *Paleohatteria*, etc.

Briefly the important characters of this specimen may be summed up as follows:

Skull stegocrotaphous, with distinct elements; epiotic probably present; the lachrymal (postnasal of Jaekel) entering into the posterior border of the external nareal opening. Surface of skull sculptured; a pineal foramen between the parietals; orbital and nasal openings not large, the latter situated near extremity of face. Premaxillae with three teeth, the first one much elongated, the second less so. Maxillae with about sixteen teeth, inserted in a single row, with a pleurodont elevation internally, and not very different in size. Mandibular teeth in a single row, biting within the upper teeth, about seventeen in number, the front ones somewhat elongated; teeth thecodont, not transverse. Palate with small teeth in two or more rows each, inserted on pterygoids and probably palatines and vomers, dependent upon the location of the sutures. Internal nares small, situated far forward. A cordiform interpterygoidal space. Pterygoids articulating with basipterygoid processes, their dilated posterior processes united with quadrates.

Vertebrae deeply biconcave, with persistent intercentra. Coracoids and large procoracoids united by suture with scapula; a supracoracoid foramen between scapula and procoracoid. Interclavicle with an elongate posterior process and dilated anterior extremity; clavicles closely attached to interclavicle and scapula; no cleithra. Ribs functionally double-headed, attached to intercentra and diapophyses. Two sacral vertebrae. Pubes and ischia expanded, plate-like, without thyroid foramen. Caudal vertebrae with ribs. Carpus with three bones in the proximal row and four in the distal, and with two centrales; tarsus with two in proximal row, five in the distal and a partially fused centrale, possibly two. Phalangeal formula probably 2-3-4-5-3, 4.

As to the identity of our specimen I can be but a little more certain than was Case. That it does not belong in the genus *Pariotichus* is certain, since there is but a single row of teeth on maxillae and dentaries. That it is not specifically identical with *Labidosaurus hamatus* I believe is equally certain, that is if Broili has rightly identified that species, and I think that he has. It presents some differences from the species *incisivus*, as described by Cope, but it may provision-

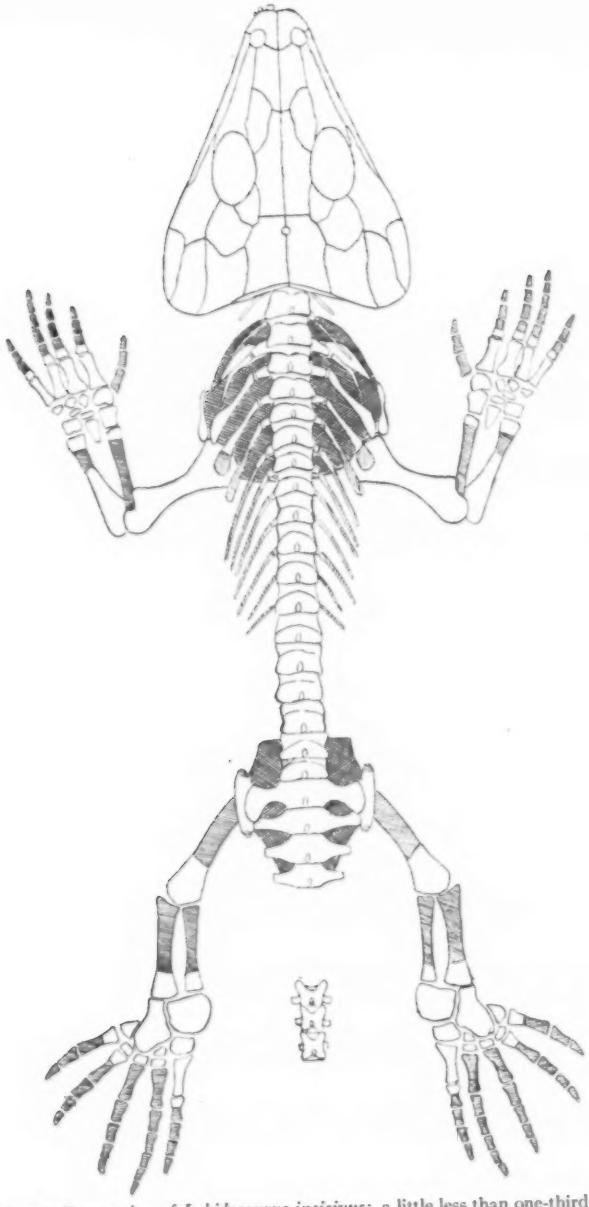

FIG. 6.—Restoration of *Labidosaurus incisivus;* a little less than one-third natural size.

ally be placed there, and in the genus *Labidosaurus* until such time as Cope's types have been examined and compared. The specific or even generic identity, however, matters little at present. The more important matter is, what relation does the form have to *Procolophon* and *Telerpeton* especially.

Boulenger has shown, forcefully I think, the relationship between *Procolophon* and *Telerpeton*,[1] about the only differences which he found being the absence of ventral ribs in *Telerpeton*. Seeley[2] and Broom[3] have, more recently, added to this the newly discovered characters of the acrodont and transverse teeth,[4] and it is on the strength of these differences, in face of the resemblances, that Broom would associate *Procolophon* with the Rhynchocephalia, *et al.*, in the superorder Diaptosauria and in the phylum Diapsida, arguing that, in any phylogenic classification the separation of the phyla should be carried back to the very beginning, even though the earliest forms may differ vastly more from the later ones than they do from those immediately preceding them. It is true that, so far, no reptile with a roofed over skull, save *Procolophon* (and of course the Chelonia) has been found to possess abdominal ribs, so commonly present among the saurocrotaphous reptiles. Indeed, of the single-arched reptiles only the Sauropterygia and Ichthyosauria have such ribs, and, carrying the argument to its extreme, Broom would unite both of these with the subclass Diapsida of Osborn, quite vitiating the original meaning of the term and requiring a new name for the modified phylum. But it is a more difficult thing to treat the Chelonia in the same way. No one has yet had the temerity to transfer the Chelonia to the Diapsida and we are forced to the inevitable conclusion that both of these reputed subclasses, the Diapsida and Synapsida, had abdominal ribs. And indeed such a conclusion is beyond dispute; certainly the oldest reptiles must have had ventral ribs and they must have been essentially Cotylosaurian in structure, for these reptiles, espe-

[1] *Proceedings of the Zoölogical Society*, London, 1904, p. 476.

[2] *Ibid.*, London, 1905.

[3] *Ibid.*, 1905.

[4] It is of interest to observe that the genera *Phanerosaurus* and *Stephanospondylus* according to Stappenbeck, have acrodont teeth placed transversely, and surely they are not also related to the Rhynchocephalia (*Zeitschrift d. deutsch. Geolog. Gesellschaft*, 1905, p. 379).

cially such forms as *Seymouria* Broili[1] are about as close to the temnospondylous amphibians, save in the palatal structure, as it would be possible to have them and still call them reptiles; unless, indeed, we accept Boulenger's rather improbable views and derive the double-arched forms from the Microsauria and the stegocrotaphous and single arched from the Temnospondyli. And here too, the Chelonia upset our best-laid schemes. Not all dinosaurs possess such ribs, and I do not think that their loss, without other important differences is of great moment. And by no means is it yet sure that the Cotylosauria, and the acleithral forms were without them. Indeed I believe that we shall find some of them with such ribs eventually.

Our "*Labidosaurus incisivus*" differs from *Telerpeton* chiefly in the sculptured skull, a character which that genus shares with *Procolophon* and *Sclerosaurus*,[2] and from *Procolophon* in that and the character of the teeth, and in practically nothing else. If *Procolophon* be admitted to a distinct order, superorder, and subclass from *Telerpeton*, what shall we do with *Telerpeton*, *Pariotichus*, *Labidosaurus*, *Elginia*, *Sclerosaurus*, etc.? They all lack the cleithrum; they are, for the most part at least, small, crawling reptiles and can hardly be united with *Pareiasaurus* nor with *Diadectes* and *Otocoelus*. Shall we erect a new order for them?

The resemblances between the pectoral and pelvic girdles of *Dimetrodon* and our present specimen are evident at a glance. But, the Pelycosauria, notwithstanding the two temporal vacuities of the skull, and its supposed membership in the Diaptosauria, have well developed cleithra, and that character must be added to the Diaptosauria as well as to the Cotylosauria and Pareiasauria!

I may add, by way of postscript, that, in a recent review of the literature of the reptilia, I find all of the older groups usually called orders have been raised in recent years by well-known writers to superordinal or subclass rank, save the Ichthyosauria and Chelonia, the two groups of all others most entitled to high rank! And most of the suborders have been elevated to orders—thirty or more. And what has been gained?

[1] *Paleontographica*, 1904.

[2] Von Huene, *Geologische pal. Abhandlungen*, X, 1902, p. 29.

# THE LOWER HURONIAN ICE AGE

A. P. COLEMAN

## INTRODUCTION

When geologists slowly became convinced of the reality of the Pleistocene glacial period it was held to be a unique catastrophe belonging to the later history of a cooling world, something without precedent in earlier geological epochs. Then, reluctantly and with astonishment, a Permo-Carboniferous glacial period, even more tremendous than that of the Pleistocene, was admitted as proved. Later still, an extensive ice age in early Cambrian or late pre-Cambrian times has been demonstrated, carrying back continental glaciers to the beginning of known life in the world.

For a number of years it has been my belief that a still earlier glacial period was the cause of the widespread basal conglomerate of the Lower Huronian; and last year, when a few scratched stones were obtained from this conglomerate at the silver-mining region of Cobalt, it seemed worth while to show that a Lower Huronian ice age was highly probable.[1]

During the past summer fresh material has been collected in the Cobalt region, including some well-preserved "soled" bowlders with ice-smoothed surfaces and well-marked striae, removing all doubt of the glacial origin of the conglomerate; and it is proposed to present here the evidence for this most ancient of known ice ages.

## THE STONES OF THE BOWLDER CLAY

It requires patience to separate the pebbles and bowlders from the hard matrix of the conglomerate, or tillite, to use Penck's term, and no very large number have been extracted, but most of them have the characteristic subangular forms of glaciated stones. As illustrations, two photographs are reproduced, the largest stone represented being about eight inches across, and having good striae on both sides and in more than one direction, one set crossing another. If the speci-

[1] *American Journal of Science*, Vol. XXIII, March, 1907.

mens collected were mixed with Pleistocene bowlder clay they could hardly be distinguished from the other stones in the clay unless perhaps by lacking the polish found on some from the Pleistocene. When it is remembered that the Lower Huronian tillite has undergone mountain-building stresses and a certain amount of metamorphism, it is astonishing to find the striations so perfectly perserved,

FIG. 1.—Lower Huronian "soled" bowlder with striations in several directions.

especially in the absence of limestone and slate pebbles, which afford the best marked glaciated stones of the Pleistocene. In the Lower Huronian tillite, felsites and fine-grained greenstones show the striae best. The illustrations given are of greenstones.

The types of rock observed are granite, gneiss, massive greenstone, green schist, felsite, and banded chert or jasper of the iron formation; all found in place in the underlying Keewatin and Laurentian, the only older formations existing in the localities. The granites are of at least three kinds, and include most of the larger bowlders, one

which was measured reaching diameters of $5\times3\times3$ feet; but the largest bowlder seen, near Temagami station, was of greenstone showing pillow structure, having diameters of $8\times5$ ft. as exposed on an ice-smoothed surface. Many of these bowlders are several tons in weight and some of the granites are miles away from the nearest known source. The smaller pebbles of felsite often show exactly the same subangular shapes with irregular well-polished surfaces as are found on pebbles of fine-grained rock in later bowlder clays.

FIG. 2.—Lower Huronian "soled" bowlder.

In many parts of the tillite the stones are sparsely distributed, sometimes several feet or even yards apart, and the red granites stand out sharply from the green-gray ground-mass. Such parts of the conglomerate present exactly the characters of till or ground moraine.

### THE MATRIX OF THE BOWLDER CLAY

The matrix of the tillite is generally graywacke, fine grained, but containing small angular particles of quartz and feldspar. It shows no stratification as a rule, though the rock as a whole may have a rude banding, pebbles and bowlders being more numerous in some layers than in others. In the original Huronian region, as described by Murray and Logan, the matrix was called slate, the rock being

referred to as "slate conglomerate," but some varieties of it were described as like quartzite or diorite or greenstone. In fact, the rock not seldom looks so massive in the field that it might easily be taken for a fine-grained basic eruptive, if it were not for the red granite bowlders scattered here and there through it; and some geologists have thought it a tuff or volcanic breccia, just as the Dwyka in South Africa was at first explained.

In reality, of course, till consists of the more or less finely ground materials of the rocks over which the ice sheet passed. If it traversed

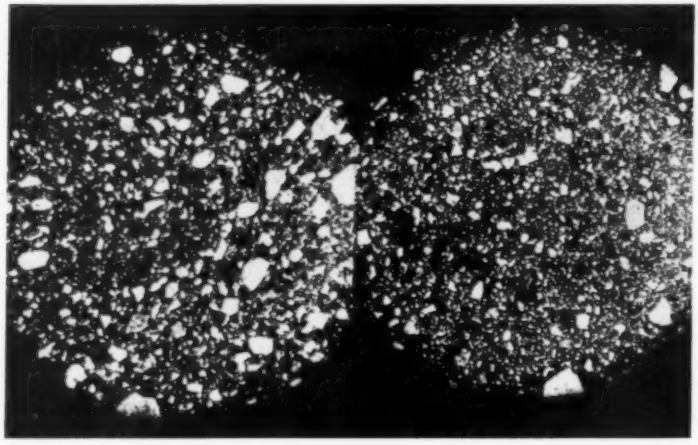

FIG. 3.—Thin sections of matrix of bowlder clays. Dwyka to the left, Lower Huronian to the right.

granite, the clayey substratum would be mixed with grains of feldspar and quartz; if it passed over fine-grained greenstones, the particles might suggest an ash rock; if the two materials were mixed, as must have been the case when the Lower Huronian glaciers moved over a surface of Keewatin penetrated by Laurentian granite and gneiss, the resulting bowlder clay would have the composition which we actually find.

The sections from near Cobalt show a small amount of very fine-grained turbid material, in which a few scales of chlorite can be recognized, crowded with angular bits of quartz, orthoclase and plagio-

clase of all shapes and sizes, and with some larger rock fragments such as diabase porphyrite or felsite or porphyritic felsite. A section from near Thessalon, north of Lake Huron, has essentially the same composition, but the minerals have been a little more rearranged.

For comparison, thin sections of the Dwyka matrix were studied, and were found to be surprisingly like those mentioned above; the only noticeable difference being the absence of chlorite scales, and a somewhat darker and less translucent ground-mass. These slight differences are no doubt due to the fact that the Dwyka conglomerate, being much younger, has undergone less rearrangement. In the illustrations the great resemblance of the two bowlder clays is shown, though by chance a rather fine-grained part of the Cobalt thin section was photographed.

### COMPARISON WITH LATER GLACIAL DEPOSITS

While much of the Lower Huronian conglomerate has the character of till, there are also phases made up almost wholly of coarse materials, bowlders, pebbles, and smaller bits of rock, with very little of the finer matrix representing clay; and these may be compared with terminal-moraine stuff.

On the other hand, the tillite sometimes passes into stratified slate with only here and there a bowlder or with no bowlders at all. In one case a bowlder nearly a foot thick was seen with the stratification bending round it as though it had been dropped into mud from floating ice.

Beside the distinctly till-like and morainic varieties of the graywacke conglomerate there are sometimes bands of crowded pebbles somewhat assorted as to size, well rounded, and no doubt water formed, corresponding to the kame materials of Pleistocene deposits. Where stratified conglomerate beds or thinly bedded slates lie between sheets of unstratified tillite, we may safely compare them with the interglacial beds of stratified sand and gravel between layers of till found at Scarboro Heights, for instance.

The known thickness of the conglomerate including the other phases mentioned is about 500 feet as measured by Professor Miller at Cobalt, which may be compared with the 400 feet of drift deposits at Scarboro near Toronto.

From the outline just given it will be seen that every feature of the Lower Huronian rocks has its close parallel in the complex of bowlder clays and sediments of the Pleistocene, though the latter are, of course, loose and unconsolidated. A comparison with the Dwyka conglomerate of Permo-Carboniferous times is more convincing still, since the Dwyka is now solid rock. Hand specimens of the two tillites might easily be interchanged by one not familiar with them. Specimens from Matjesfontein in Cape Colony or N'gotsche Mountain in

FIG. 4.—Polished pebbles in ancient till. Dwyka to left, Lower Huronian to right.

Natal placed beside specimens from Cobalt or north of Lake Huron present the same fine-grained gray matrix with angular bits of quartz and feldspar, or fragments of granite, or small polished pebbles of felsite. As shown before, even thin sections under the microscope present no material differences.

In fact, the only important point of distinction between the two tillites is the comparative ease with which the Dwyka matrix weathers, setting free the inclosed stones; while in the Cobalt rock matrix and pebbles weather at nearly the same rate. In both tillites when fresh it is hard to break out the stones by the hammer, since the fractures

are apt to run impartially through pebble and matrix. One cannot but be struck by the close resemblance the two rocks have to one another in every particular. Every argument which goes to prove the glacial origin of the Dwyka conglomerate applies equally well to the Lower Huronian conglomerate of northern Ontario, with one exception.

No underlying striated surfaces or *roches moutonnées* have been found beneath the Lower Huronian tillite; while beautifully glaciated surfaces are displayed beneath the northern Dwyka. It should be remembered, however, that no such surfaces have been found under the southern Dwyka, where the conglomerate passes downward into

FIG. 5.—Dwyka tillite to left, Lower Huronian to right.

shale, e. g., near Matjesfontein. It may be recalled also that at many points in North America no ice-smoothed surfaces are found under Pleistocene bowlder clay. This is the case at Toronto, where the underlying Hudson shale is never polished or striated but seems almost to blend upward into the lowest sheet of bowlder clay. The absence so far as known of *roches moutonnées* under the Lower Huronian conglomerate is then no valid argument against its glacial origin.

### EXTENT OF THE LOWER HURONIAN GLACIATION

The striated stones referred to earlier in this paper were obtained at two points three or four miles apart, in a cutting on the Temis-

caming railroad near mile 100, and on the Trethewey silver-mining location; both localities being included in the same area of conglomerate as mapped by Professor Miller. Search was made for glaciated stones near Temagami, twenty-eight miles southwest, where the conglomerate is prominent in railway cuttings, but the rock proved to be somewhat squeezed and decidedly more metamorphosed than at Cobalt, so that the stones broken out of the matrix showed no well-preserved surfaces. In every other respect the conglomerate is exactly like that of the silver region.

Conglomerates of the same age are known from almost every area mapped as Huronian in Ontario, from Lake Temiscaming on the east to Lake-of-the-Woods on the west, a distance of more than 700 miles; and from Lake Huron on the south to the north end of Lake Nipigon, 250 miles. In my own field-work such conglomerates have been studied at more than twenty localities scattered over the great region.

In most cases the conglomerate has proved to be far more metamorphosed than at Cobalt, often transformed into schist conglomerate with the pebbles and bowlders flattened into lenses. In such cases the resemblance to bowlder clay is lost, though the varied size and lithographical characters of the stones, and often also their wide spacing in the matrix, are suggestive of a glacial origin.

In several places, however, the Lower Huronian conglomerate is almost as unchanged as at Cobalt, for instance, near Lake Wahnapitae, east of Sudbury, and at various places in the typical Huronian region north of Lake Huron. Years ago these impressed me as resembling bowlder clay, but at that time no striated stones were found.

These areas of characteristic tillite occur at points 200 miles apart, about in lat. 46°. Of the other conglomerate areas one can only say that in all probability they are glacial also. In some places where the pebbles form closely crowded bands and are fairly uniform in size they are probably water formed, and may be explained as kames or marginal gravel beds like the Saskatchewan gravels of Alberta, glacial materials rearranged by rivers or by wave action.

Very similar bowlder conglomerates are described from Huronian regions not visited by the present writer. Dr. Bell maps schist conglomerates in northern Quebec, the most easterly at Mattagami Lake, in long. 77° 30′, and Mr. Low describes bowlder conglomerates from

southern Labrador. Mr. J. B. Tyrrell has found them on Pipestone and Cross lakes northeast of Lake Winnipeg, in long. 97° 30′, and Mr. Stewart Dobbs has described them from Manitou River near Hudson Bay, in lat. 57° and long. 92°. Huronian conglomerates exist, then, at points 1,000 miles apart from east to west and 750 miles apart from south to north; and there is little doubt that areas still remain to be discovered in the far north. To the south of the Great Lakes very similar Lower Huronian conglomerates are known in Minnesota and Michigan, and it is altogether probable that other areas to the south are buried beneath the Paleozoic sediments. Supposedly Huronian conglomerates have been described also from the Avalon Peninsula of Newfoundland.

So far as North America is concerned the probable extent of glaciated territory is comparable to that of the Permo-Carboniferous and the Pleistocene. In the Old World also there are very ancient bowlder conglomerates which may be of the same age and origin. Sir Archibald Geikie says of such bowlder beds in Scotland that, "where the component blocks are large and angular, as at Gairlock, they remind the observer of the stones in a moraine or in bowlder clay."[1] Similar pre-Cambrian conglomerates are found in Scandinavia and in Finland; and probably also in India and China; but whether they are equivalent in age to the Lower Huronian of Canada is uncertain.

## GENERAL CONCLUSIONS

It has been shown that convincing evidence of glacial action in Lower Huronian times has been found in the Cobalt region of northern Ontario, the glaciated stones obtained there furnishing the final proof; that exactly similar conglomerates occur at points 50 and 200 miles farther west, though no striated stones have yet been found in them; and that bowlder conglomerates, once probably of the same kind, but now squeezed and rendered schistose, occur in every important tract of Huronian in North America, suggesting strongly that the whole region was glaciated at that time.

Moved by conservatism and having in mind the long-accepted theory of a molten earth slowly cooling to its present temperatures, some geologists may object to the conclusions given above and may think that too much stress has been put on the few scratched bowlders

[1] *Text Book of Geology*, p. 705.

thus far obtained. In reply it may be stated that the striated stones are merely the climax of the evidence in favor of a Lower Huronian ice age. The character and extent of the conglomerates themselves are unaccountable on any other theory. If these conglomerates were known only from a few small patches, one might perhaps invoke crushing and faulting, or talus formation, or exceptionally heavy river currents to account for them; but when one finds that they often cover many square miles, with thicknesses of hundreds or even more than a thousand feet, and occur in every Huronian district with the same characteristics, any such cause becomes incredible. It must be remembered that, large as the conglomerate areas are, they represent only remnants of a much more widely spread formation; for the greater part they are merely bands caught in synclines during the elevation of the Archaean mountain ranges. In the beginning the conglomerate must have been far more extensive and was perhaps continuous over the hundreds of thousands of square miles where it is now found in scattered patches. The only comparable bowlder-bearing formations known are the bowlder clays of Permo-Carboniferous and Pleistocene times. Under these circumstances the burden of proof lies with those who oppose the glacial origin of the Lower Huronian conglomerate, and not with those who support it.

Since there is only one older sedimentary formation, the Keewatin, below the Lower Huronian, the glacial period just described comes very close to the beginning of known geological history. The surface of North America was much colder then than at present, and there is every reason to think that the earth's climates were then, as now, controlled from without, and not influenced by stores of internal heat much greater than in recent times. The earth has not cooled down from the earliest ages known to geology, but may have kept a uniform temperature, or may have been warming up as the ages advanced.

If a Lower Huronian ice age is admitted, geologists should cease to speak of the earth as once a molten globe, and to begin historical geology with its cooling so as to form a solid crust, on which, much later, water could condense, and sedimentary deposits be formed. There is no geological evidence of any such early history, and we should not cling to an outworn nebular hypothesis which the astronomers themselves are throwing overboard.

# *STUDIES FOR STUDENTS*

## RELATIONS BETWEEN CLIMATE AND TERRESTRIAL DEPOSITS[1]

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CONCLUSIONS ON RELATIONS OF CLIMATE AND EROSION.

### GENERAL INTRODUCTION

The environment of the lands may be classified into three fundamental and independent factors—the relations to the surrounding seas, the topography which forms their surfaces, and the climates

[1] Presented in abstract before the Geological Society of America, December 26, 1906. The term terrestrial deposits has special reference here to fluvial and pluvial deposits rather than glacial, lacustrine, and eolion deposits.

[2] Parts II and III will be published in later numbers.

which envelope them; each of major importance in controlling the character of the lands and the evolution of their inhabitants.

The relations of the lands and seas of previous ages is the one of these environmental conditions which has been longest under investigation, since the seas have left a positive record of their invasions in the form of marine sedimentary strata and the remains of the inhabiting organisms.

The topographic changes of the lands of earlier ages give problems of equal importance, both in connection with the history of crustal movements, as sources of the sedimentary rocks, and in the evolution of terrestrial life; now raising mountain barriers and again opening fields for migration and expansive evolution. But until recent years the problem of restoring earlier land-forms had not attained to a systematic and scientific state. That knowledge of the topographic history of the land should be slower in development than the relations of land and sea is seen to be natural when it is considered that each erosion surface is made only through the destruction of the preceding land-form, with the result that the earlier leaves in the volume of land history, contrary to that of the sea, are destroyed in the making of the last, and it is only through processes of deduction that the earlier stages may in a general way be restored.

The third great problem of terrestrial environment, the succession of ancient climates, lags still farther behind in development, but is no less important in a complete understanding of the history of the earth and its inhabitants. This lack of development is doubtless due to the intangible nature of climate and the absence of direct record of its geologic changes. When it is considered, however, how fundamental are the relations of continental deposits to the climates in which they are formed, it is seen that the record of geologic climates, while indirect and largely awaiting interpretation, is nevertheless in existence.

The significance of salt and gypsum deposits on the one hand or of glacial deposits on the other is of course universally recognized, but these are the marks of climatic extremes. The causes of climatic variations, as distinct from the record, have likewise in recent years received a great amount of attention, with the result that a considerable body of knowledge has taken the place of previous speculation. But

what are the geologic records of that great variety of climates which, excluding the desert belts of the world, reach at present from the equator to the polar zones? They may be studied most favorably in ancient terrestrial deposits, since these are free from the contributory record of the sea, and, as it is the problem of the average climates which it is sought to investigate, it is especially in ancient fluvial and pluvial deposits rather than in deposits of desert or glacial origin that the record is to be found. In such river deposits each stratum represents an old land surface, the seat of abundant animal and vegetable life, sealed and protected instead of destroyed, by the making of the succeeding land record. In such deposits the evidence most usually studied is that from the teeth and feet of animal fossils, or the nature of vegetable remains. But many continental deposits are without fossils and many groups of organisms show a wide climatic range, so that it is very desirable that other features constantly present, such as the chemical, textural, and structural characteristics of the strata, should be available for the climatic interpretation. The significances of such features have of course not entirely escaped attention, the presence of red in shales or sandstones is sometimes cited as evidence of derivation from a deeply decayed and highly oxidized regolith; or the existence of a conglomerate whose pebbles are of vein quartz as evidence of the thorough decomposition of an ancient soil. But such statements have been made without a preliminary investigation into all the possible modes of origin, and it will be found that in the following pages other interpretations are pointed out. The problem, then, in the present paper is to separate the influence of the climatic and topographic factors in the making of fluviatile continental sediments. In seeking for data to draw the lines more closely it is found that the relations of climate to the nature of the land waste and river sediments have attracted the attention of relatively few explorers and scientists. Such exceptions must, however, be noted, as Blanford and Oldham, Walther, Hilgard, Merrill, Russell, Davis, and Huntington. These men, with a few others, have largely supplied the data which make the following articles possible.

The mode of treatment adopted is to divide the influence of climate upon fluvial and pluvial deposits into three parts: first, the influence on the kind and quantity of the material eroded, allowing for the

effects of various land reliefs and lithologic characters; second, the influence upon the sediments in the region of deposition, allowing for the various geographic conditions under which the deposit may take place; third, the relations of climate to transportation by running water. Each of these relations forms a largely independent problem and by the concurrence of evidence from them other factors may be eliminated and a fair degree of certainty attained in regard to the climatic conditions existing during the formation of ancient stream deposits.

The first part, dealing with the relations of climate to erosion, is necessarily largely physiographic and, in the case of sediments which are carried long distances, is of less final influence than the conditions under which the sediments are deposited and those of the preceding transportation. The purpose of the whole paper is, however, not physiographic but stratigraphic. For this reason it is the relation of physiography to erosion and the consequent supply of sediments which is dwelt upon, rather than the discussion of the land-forms as an end of investigation. Owing to this somewhat unusual use of physiography as well as the desire to make the discussion more complete for students in other branches of geology, it is necessary to go over some ground which is familiar to physiographers. Even from a physiographical standpoint, however, it is thought that a brief general discussion of all the climatic factors influencing erosion is not without its value, since it is found to suggest some new points of view upon several old problems.

For the elaboration of the second and third parts, those upon the relations of climate to terrestrial deposition and the preceding transportation, sufficient reason is found in the existence of diverse views held by many working geologists upon the significance of various stratigraphic characters; and, furthermore, in the general conclusion that climate is a factor comparable to disturbances of the crust or movements of the shore line in determining the nature and the variations in the stratified rocks of continental or off-shore origin, thus playing a part of large, though but little-appreciated, importance in the making of the stratigraphic record.

The investigation was instituted to see to what extent profound climatic variations, complicated doubtless with some tectonic movements, could account for the great contrasts in the Lower and

Upper Carboniferous formations of eastern Pennsylvania; formations which had been found by the writer from field investigations to be continental in origin and therefore their contrasted features not to be attributed to changes in the relations of land and sea. As an illustration of the importance of the climatic factor in sedimentation, it may be stated that an application of the conclusions of this paper goes to show on several lines of evidence, which it is hoped to publish in the near future, that the changes from the red beds of the Catskill formation, several thousand feet in thickness, to the gray Pocono sandstones with a maximum thickness of 1,200 to 1,300 feet, then to the sharply contrasted red shales and sandstones of the Mauch Chunck, 3,000 feet in maximum thickness, and back to the massive white conglomerates of the Pottsville conglomerate, 1,200 feet in maximum thickness, followed by the coal measures, are all the result of increasingly wide swings of the climatic pendulum which carried the world from Upper Devonian warmth and semi-aridity to Upper Carboniferous coolness, humidity, and glaciation.

## PART I. RELATIONS OF SEDIMENTS TO REGIONS OF EROSION

### Introduction

The larger rivers of the world, of which the Missouri and the Nile may be cited as striking examples, frequently rise in a climatic zone entirely distinct from that of the mouth. Such rivers usually flow for some hundreds of miles across low-lying country after escaping from the mountains, and carry nothing coarser than fine sand in their lower reaches, the dominant deposits over the surfaces of the large deltas being a great volume of clay and loam. That the climatic conditions under which the sediment is supplied at the source, has an appreciable influence even in these extreme cases is shown by Walther, who points out that the alluvium of the large tropical rivers is usually red in color while that of the Ganges and Mississippi, brought to the limits of the tropics from temperate regions, is gray instead of red.[1]

In shorter river systems, however, not only is the climate of the headwaters more closely related to that of the alluvial plains, but both the climatic and geographic conditions existing over the former region

[1] *Einleitung in die Geologie*, 1894, p. 815.

will notably modify the character of the sediments laid down upon the latter. It is necessary, therefore, to consider geographic factors as well as climatic, and to begin at the river's source. The geographic and topographic relations in the regions of erosion existing during a distant epoch cannot, however, be directly ascertained by observation of the existing rocks, as may the conditions in the region of deposition. These relations may, furthermore, in their effect upon the alluvium, simulate and mask the climatic effects to some extent. As a result it is impracticable to make fine distinctions in climatic cause over the regions of erosion, and in general only those types of climate which markedly affect the quantity and kind of land waste need be considered. These may be classified as of four types, as follows: warm and rainy, warm and arid, cold and rainy, cold and arid; truly glacial climates being excluded from the scope of the paper.

## Character of Rocks Supplying Sediment

### similar effects from lithologic and climatic causes

In alluvial deposits the nature of the rocks supplying sediment is a matter of importance. A basic igneous rock, for instance, even in a subarid climate, such as exists over the Deccan of India and the northwestern United States, may give rise to a large amount of ferruginous clay containing mineral fragments other than quartz, and of various sizes. After sufficient transportation and sorting such clays would be the dominating deposits, and except for a greater content of lime, must closely simulate clays from well-decayed normally acidic rocks of a more pluvial climate. Again, a region of calcareous rocks will furnish a large amount of lime in solution, and this, by cementing the alluvium of the delta, as for example, in that of the Rhine, may cause the river deposits of a humid climate to resemble in this respect the alluvium of subarid regions. Further, the material derived from rocks of a sedimentary nature owes part of its character to a previous cycle of erosion and deposition under different climatic and geographic conditions.

### elimination of lithologic factors

This possibility of confusion between climatic and lithologic influences over the region of the headwaters may be obviated to a large extent, first, through the determination of the source of sediments and, if

this region is still above the sea, observation as to the kind of rocks now outcropping and probably present at that time; second, by a detailed study of the nature of the sedimentary particles (Sorby, Bonney, and others have shown to what an extent microscopic study of sedimentary materials may indicate the lithologic nature of the source);[1] third, by comparing the particles in deposits of dissimilar nature but of similar coarseness or fineness accumulated in successive epochs in the same region, and presumably from the same general source. For example, the material forming the coal-measure shales and sandstones of eastern Pennsylvania is of about the same grain and doubtless from the same ultimate source as the Upper Devonian and Subcarboniferous shales and sandstones of the same region. Scattered microscopic particles of feldspar in one of these formations and an absence of them in another may be taken as due to a difference in topographic or climatic conditions of origin in the region of the headwaters, and not due to derivation from unlike lithologic sources.

The preceding statements regarding the influence of the sedimentary source must not be allowed, however, to give an exaggerated importance to the lithologic character of the original rock; important near the regions of erosion, it diminishes with the distance of transportation. In regard to this matter E. W. Hilgard states:

> Alluvial soils are to a certain extent dependent upon the character of the rocks and surface deposits occurring within the drainage area of the depositing stream. As a rule their composition is much more generalized; and their character as to the relative proportions of sand and clay is essentially dependent upon the velocity of the water current.[2]

This diminution in influence of origin with distance of transportation is due partly to the contributions from tributary streams coming from somewhat different geologic provinces, partly to continued decomposition of the sediments during transportation, tending to leave similar insoluble residues, but largely to the sorting action of the water in separating unlike constituents. The sediments from dissimilar geologic provinces, therefore, are apt to consist of similarly classified products, such as ferruginous clays and siliceous sands,

[1] T. G. Bonney, Presidential Address, Section C—Geology, *Proceedings of the British Association for the Advancement of Science*, 1886, pp. 601–21.

[2] *Soils in the Humid and Arid Regions*, 1906, p. 13.

though the total amounts of these may hold to each other entirely different proportions. It is to be concluded that the nature of the parent rock is best reflected by the nature of the sediment where this is but slightly transported, but may show in minor degree for long distances.

### Relations of Rainfall and Topography to Erosion

#### Interrelations of topographic and climatic causes

The relation between the topographic character of the land and the resulting sediment has been discussed by Bailey Willis, who points out that in the youthful topographic stages rock-breaking as a method of erosion dominates over rock decay; in topographic old age the reverse is true. The former supplies a maximum of unleached mechanical sediments; the second, a maximum of rock matter in solution.[1]

Under arid climates, however, and to a lesser extent in cold climates, the material derived from the rocks is characterized by the same dominance of disintegration over decomposition, even in regions of topographic maturity or old age; sun and wind serving to erode and transport rock material without producing rock decay. When swept to a distance by rivers and laid down upon flood-plains, there may be strong chemical resemblances between the sediments originating under such dissimilar conditions and consequently a resulting confusion between distinct topographic and climatic causes.

Furthermore, topography and climate not only have independent and sometimes similar effects upon the sediments, but have mutual effects upon each other. On the one hand, topography in its major features modifies climate, on the other, climate materially affects the minor features of topography.

Different kinds of climate and topography may, therefore, lead to various results, and a change in either the climatic or topographic factor in the regions of erosion may be expressed by a change in sedimentation over a distant flood-plain. In analyzing and separating these interrelations and simulated effects three kinds of topography may be considered: first, young and mountainous topography, characterized by deep and precipitous valley walls, high elevations,

[1] Studies for Students, "Conditions of Sedimentary Deposition," *Journal of Geology*, Vol. I, 1893, pp. 476–80.

and a maximum of naked rock surface; second, mature mountainous topography, marked by broadly V-shaped valleys, long slopes covered with soil and talus, and lower rounded summits; third, old topography, with widely opened, flattened valleys holding meandering rivers and with the interstream spaces no longer mountainous, but reduced to rolling hills. The four kinds of climate to be considered have already been mentioned as combinations of pluvial and arid, warm and cold.

### YOUNG TOPOGRAPHY AND VARIOUS CLIMATES

Young and mountainous topography, as is well known, produces an intensification of climatic effects and a heightening of the climatic contrasts of nearby regions, inducing an extreme precipitation, often largely as snow, upon the windward slopes and to a lesser extent upon the leeward slopes, and resulting in semiarid or truly arid tracts farther to leeward. Rapid erosion will prevail in both regions, but the results are of essentially different characters. Where the precipitation is regular and not violent, that is, not as snowfall or irregular cloud-bursts, the rivers and valley walls tend to become graded, vegetation holds the soil to the slopes, and interstream erosion over the soil-covered regions is diminished, and the material carried away by the rivers is finer[1] and more thoroughly leached of its soluble elements.[2] Over the steeper slopes and along the streams, however, erosion may go forward with immense rapidity. The waste which is held within the region is, therefore, largely held as soil, on the moderate slopes, and not as detritus, and upon any climatic change which shall diminish the effectiveness of the vegetative covering is liable to be swept away with geological suddenness as a flood of clay, sand, and gravel.

On the side of the mountains possessing a subarid or arid climate, the waste is swept away as soon as disintegration frees it from the rock, and is largely stored in interior basins or on piedmont slopes. This material adjacent to the mountains is but little decomposed, has less true clay, and on the whole is coarser than the similarly situated waste of milder or more pluvial climates. As examples

[1] E. Huntington, *Explorations in Turkestan, with an Account of the Basin of Eastern Persia and Sistan*, Carnegie Institution Publications, No. 26, 1905, p. 269.

[2] E. W. Hilgard, *Soils of the Humid and Arid Regions*, p. 413, 1906.

may be cited the coalescent gravel fans of Persia forming the "skirts of the mountains," and the detrital slopes of the mountains in New Mexico and Arizona.

As a description of the character of erosion in the heart of the desert mountain region of Arizona may be cited a paragraph by Ransome, who, writing of the Globe copper district, says:

> With the exception of the timbered slopes of the Pinal Mountains, and a few alluvial areas along the main arroyos, the surface of the region is almost destitute of soil. The scanty shrubbery, and the sparse grass and herbage which spring up with wonderful rapidity after the rains, are insufficient to prevent such soil as may form from being quickly washed away. The humus acids, which in moister climates and beneath the covering of soil aid in rock decay, have in this region little opportunity to form or to attack the rocks. The latter crumble or flake under the influence of sharp atmospheric changes, and these fragments are rapidly carried into the valleys. The granitic masses crumble into particles of quartz, flakes of mica, and angular fragments or crystals of comparatively fresh feldspar. The rains acting on this disintegrated material soon wash it down to the larger streams, which carry off the quartz and mica. The larger fragments of feldspar often build up alluvial fans at the mouths of the small ravines heading in a granitic area, and such fans are remarkable for the purity and freshness of the feldspathic material which composes them, the numerous cleavage faces flashing brightly in the sun. Excellent examples of these fans were observed along Pinto Creek, north of Horrell's west ranch. They are evidently transient phenomena, accumulating until an exceptionally wet season causes Pinto Creek to rise and sweep them away.[1]

The rainfall varies in adjacent parts of this region and in successive years, the amounts ranging from 11 to 20 inches per year, a considerable proportion falling as rain during the sudden and violent downpours which are common in July and August.[2]

Upon a climatic change causing more voluminous streams to flow across the piedmont slopes or drain the interior basins, the stream profile for equilibrium is altered, a large amount of coarse, unleached, and incoherent waste may be quickly swept downstream, even to the delta, and be deposited either upon its upper surface as partly subaerial products, or swept to the front, building the delta farther seaward.

[1] *Geology of the Globe Copper District, Arizona*, Professional Paper No. 12, U. S. Geological Survey, 1903, p. 21.

[2] *Op. cit.*, p. 20.

### MATURE TOPOGRAPHY AND VARIOUS CLIMATES

Upon a mountain region becoming mature, its lower summits and rounded slopes exercise less effect upon the climate, which now becomes less accentuated and contrasted in nearby regions, and the rainfall may extend for some distance beyond the crest line. Broad extents of continental lands are here more important as modifiers of the climates natural to the several zones. There is still a marked relation in detail, however, between the climate and the surface. The problem has been studied in Persia with particular reference to climate by Huntington, who states:

> A prominent characteristic of the mature mountains of Persia is their nakedness, roughness, and sterility. In a young country it is to be expected that there shall be large areas of naked rock, but in a mature country, if the rainfall is abundant, most of the surface, except the immediate valley sides, is graded, and thus covered more or less deeply with soil. Eastern Persia, however, is so arid that the ordinary state of affairs is reversed. All the mountains, whether young or mature, are characterized by nakedness. Graded slopes are not a feature of maturity in an arid climate.[1]

The valleys and basins are deeply filled with waste and the area of exposed rock is not, however, so great as during the period of youth.

The differences in the chemical and physical composition and the place of storage of the rock waste of arid and well-watered mountains become emphasized with maturity. This heightened contrast is due to the larger and deeper mantle of rock waste exposed to the particular climatic influences and moving more leisurely from its original source to the reach of the streams. The contrast in kind of products due to the climatic difference is well brought out by Hilgard,[2] who points out that—

> since kaolinization is also a process of hydration, the presence of water must greatly influence its intensity, and especially the subsequent formation of colloidal clay; so that rocks forming clay soils in the region of summer rains may in the arid regions form merely pulverulent soil materials. Many striking examples of these differences may be observed, e. g., in comparing the outcome of the weathering of granitic rocks in the southern Alleghenies with that of the same rocks in the Rocky Mountains and westward, especially in California and Arizona.

[1] *Explorations in Turkestan*, Carnegie Institution Publications, No. 26, 1905, pp. 247, 248.

[2] *Soils*, 1906, p. 47.

The sharpness of the ridges of the Sierra Madre, and the roughness of the hard granitic surfaces, contrast sharply with the rounded ranges formed by the "rotten" granites of the Atlantic slope, where sound, unaltered rock can sometimes not be found at a less depth than forty feet; while at the foot of the Sierra Madre ridges, thick beds of sharp, fresh granitic sand, too open and pervious to serve as soils, cover the upper slopes and the "washes" of the streams, causing the latter to sink out of sight. A general discussion of the kinds of soils formed from the various rocks must, therefore, take these differences into due consideration.

The lack of decomposition and the dominance of disintegration in desert regions, giving rise to fresh and unweathered sands, have also been emphasized by Walther, who shows that insolation breaks up crystalline rocks into a rubbish of crystals scarcely altered chemically.[1] Merrill and others have abundantly confirmed this as a principle dominating the production of rock waste in arid climates.

#### OLD TOPOGRAPHY AND VARIOUS CLIMATES

Regions topographically old are of lessened importance from the view-point of the mechanical sediments of running water, but little waste being contributed to the deltas and the seas and the conditions for limestone formation approaching close to the shores. In the old age of the humid region the blanket of decomposed rock becomes universal and increased in thickness, giving rise upon erosion to fine-grained and well-decomposed silts. In the arid regions, on the contrary, the waste in the rock basins diminishes in thickness through wind and water erosion and the desert becomes finally covered with a thin gravelly or sandy mantle still characterized by lack of decomposition. In the old age of arid regions, as shown by Passarge, wind erosion becomes increasingly more important than water erosion, since the water loses its force upon the flat desert surface, while the action of the wind does not diminish in intensity. The products of erosion in old age, therefore, are chiefly wind-borne loess and dune sand, possessing distinctive qualities and a different distribution from sediments of fluvial and pluvial origin.

### Relations of Temperature and Topography to Erosion

#### EFFECTS OF TEMPERATURE VARIATIONS ON VEGETATION AND SOIL RETENTION

Besides the relations dependent upon rainfall, those dependent upon temperature may also be considered. In general, increased cold

[1] *Einleitung in die Geologie*, 1893–94, pp. 546–47.

with stable precipitation but without glaciation has been considered geologically equivalent to stable temperature and increased rainfall, since the evaporation is decreased and the run-off consequently increased, but an analysis of the problem would appear to show that in its ultimate stratigraphic effects it is much more complex than this, a complexity which has been recognized possibly for the first time by Chamberlin and Salisbury,[1] who state:

> The cold climate probably affected erosion, and therefore deposition in another way, for the reduction of temperature was probably attended by a reduction of vegetation, and any diminution of vegetation must have reflected itself in increased erosion. The reduction of vegetation was probably greatest just where erosion was most readily stimulated, namely, in the higher altitudes. The importance of this consideration has perhaps not been duly considered.

On the other hand, a marked rise in mean annual temperature without change in precipitation will, in a region already under optimum climatic conditions for vegetation, be equivalent to a movement toward aridity. This is seen on comparing tropical deserts with those of the temperate zone, where in the former a precipitation twice as great may not prevent the existence of a similar aridity. The results in the decrease of the vegetative hold upon the soil and a consequent increased erosion, provided there is sufficient run-off to remove the rock waste, will be similar to the results of a change toward unfavorable cold.

It may be stated in conclusion, therefore, that any marked variation of temperature away from that which in combination with the rainfall gives the optimum conditions for vegetable growth will result in a loosening of the soil and a corresponding increase in the rate of erosion. The diminished area of rock covered by the soil and the thinner covering where it does exist will, in combination with the lessened amount of organic matter, result in an increase of disintegration and a relative diminution of rock decay.

### EFFECTS OF INCREASED COLD

*On frost action and erosion.*—Not only is the balance of the vegetative covering to erosive power disturbed, but during periods of increased cold the frost action over exposed rock surfaces becomes more energetic. Its intensity at high mountain elevations or in high

[1] *Geology*, Vol. III, 1906, p. 453.

latitudes has been pointed out by Walther,[1] by Russell,[2] by Merrill,[3] and others, and reliance upon this action has been employed by Oldham to reach the conclusion as to the existence of a period of cold, but one not attended by glaciation during the deposition of the Panchet group, early Mesozoic of India.[4]

It has been thought by some that perhaps a rigorous winter climate does not promote corresponding disintegration, since during a considerable portion of the year there may be no thaw. Observation seems to indicate, however, that with increase of altitude or latitude the results of frost action become progressively more pronounced. The explanation is apparently to be found in the fact that although surface melting and refreezing may be absent, frost action is at such times penetrating constantly deeper. The period of daily freezing and thawing will in this case occur at the two ends of the winter season instead of the middle and on account of the greater daily insolation and nocturnal radiation the effects may be as pronounced as during a somewhat longer period near the winter solstice.

If the cold becomes so great, however, as to result in a perpetually frozen substratum, the disintegrative action will presumably become less instead of greater, but such a condition does not exist at present except under polar climates. It is not one which would, so far as known, become widespread even at times of glaciation, and is the consequence of a climatic extreme which need hardly be considered.

The effects of increased cold in regions of no glaciation must consequently be either one of two kinds, depending upon whether frost action or snowfall is increased: frost tending to make more rock waste; snow tending to prevent frost action and by its melting to carry waste away.

In climates possessing but little snowfall, increased variations of temperature and increased frost action will be the most marked results of a change to a colder climate. In regions of exposed rock

[1] *Einleitung in die Geologie*, 1893–94, p. 559.

[2] *Notes on the Surface Geology of Alaska*, Bulletin of the Geological Society of America, Vol. I, 1890, pp. 133–37.

[3] *Disintegration and Decomposition of Diabase at Medford, Mass.*, Bulletin of the Geological Society of America, Vol. VII, 1896, pp. 349–62.

[4] *A Manual of the Geology of India: Stratigraphical and Structural Geology*, 2d ed., 1893, p. 201.

surfaces, and therefore typically in rugged mountainous regions, this must result in a more rapid disintegration of the naked rock masses and an increased supply of talus to the streams. Under the small precipitation postulated, however, the streams will be only slightly increased in volume by the decreased evaporation, and presumably not able to carry away the excess of load. The weakening of the vegetative covering over the soil-covered slopes would work to the same end, but in a desert region this factor would be absent. The tendency of the increased disintegration would be to build up piedmont slopes, whose rate of growth would diminish or even cease upon a return to less rigorous winters. The effects of increased cold in many cases may, therefore, disturb the balance of erosion to transportation, in the same way as a change toward more marked aridity without increased cold.

*The Gila conglomerate of Arizona.*[1]—As an example of a Pleistocene formation which it was thought might be due to some such cause, the writer has examined the literature on the Gila conglomerate of Arizona, a formation now dissected in many places to the depth of a thousand feet and attaining its maximum development in the upper portions of the valleys of New Mexico, Arizona, and southern California. The specific nature of the climatic or tectonic changes which could have resulted in its production does not seem to have been fully discussed, the only definite opinion expressed being that of Lee that in so far as climate was a factor in the accumulation of this upland débris in southern California and Arizona, it was in the nature of a desiccation.[2] Others consider that their Pleistocene age and the finding in New Mexico of contemporaneous elephant, horse, and tapir bones are an indication of the accumulation of similar New Mexican deposits during an epoch of moist climate in the early Pleistocene.[3]

An examination of the literature showed that the relations of the two divisions of the Gila conglomerate, the volumes and relative

[1] The writer hopes to publish a fuller discussion of this subject than can be given here.

[2] "Underground Waters of Salt River Valley, Arizona," *Water Supply and Irrigation Paper No. 136*, U. S. Geological Survey, 1905, p. 115.

[3] George B. Richardson, *Science*, New Series, Vol. XXV, 1907, p. 32.

ages of each, corresponded with the two epochs of glaciation which were pronounced in Utah and Nevada and the two periods of expansion of Lakes Bonneville and Lahontan. This taken in consideration with the place of deposit of the gravels, in the upper portions of the river valleys, leads to the view that the Gila conglomerate originated from an increase in the ratio of erosion to transportation, due to the severe cold and consequent frost action of the glacial times, without a correspondingly large increase, in this arid region, of precipitation. The ultimate cause of the accumulation under this view was greater cold and not a desiccation, since the precipitation was doubtless somewhat increased as shown by the mammalian bones. Any conclusion in regard to the exact cause and correlation is, however, of minor importance in comparison with the broader one that the deposit is due to climatic causes rather than those of a local or regional tectonic nature. If this conclusion be well founded it is seen that in this desert region with mountainous topography climatic changes have been a sufficient cause to result in the laying-down over wide areas adjacent to the higher mountains of a conglomerate formation largely over a thousand feet in thickness, justifying the statement that climatic changes may result in sedimentary formations as important as those due to tectonic or oceanic causes.

*Effects of increased cold on snowfall and erosion.*—In regions where the increased cold results in the precipitation of snow which previously had fallen as rain, frost action and also chemical action may not be increased, and the chief results of the spring floods resulting from the melting snow may be an increase of transportative power. The protecting power of snow against both disintegrating and decomposing agencies has been cited by Salisbury as probably contributing to the fresh and unweathered appearance of the Wisconsin drift of the Bighorn Mountains when compared with that of the continental interior.[1]

In mountainous regions such as the Sierras, where the snowfall is markedly greater at the higher elevations, the floods produced by the spring melting are not proportionately augmented upon reaching the lowlands, and deposition of the excess load is to be expected

[1] *Geology of the Bighorn Mountains,* Professional Paper 51, U. S. Geological Survey, 1906, p. 87.

upon the piedmont slopes. The same is found to be true on the eastern slopes of the southern Andes on portions of which aggradation is now in active progress. An increased snowfall without actual glaciation, especially if it takes the place of what had previously fallen as rain, may therefore result in the waste being carried farther before deposition, accompanied by a dissection of the upper portion of the piedmont slope, the results being opposite to those of increased frost action. In regions of less elevation, however, the rainfall and snowfall are nearly the same upon upland and lowland, the volumes of the streams are increased as they flow toward the sea, the sediment once picked up is carried through by the river, and as a result of increased snowfall an increased erosion may take place without the tendency to aggradation in the middle portions of the streams. Such an effect is in many ways equivalent to a change toward a more voluminous or at least more concentrated regional rainfall. In the preceding statements snow and frost action have been considered separately. In nature, however, there may be various combinations of these agencies. Increased cold may lessen the hold of the vegetation on the soil, the latter, saturated in the spring with snow water, may be more rapidly removed, and an opportunity be given for increased frost action. Consequently, while a greater amount of sediment may be carried through to the lower portions of the river system, aggradation may yet take place to some extent in the upper portions. Some such change of relations seems to have occurred during glacial times over certain regions outside of the limits of glaciation, since terraces and fans of glacial age characterize the upper portions of many river systems. These conditions find their maximum development at the present time in the subglacial polar or mountain climates. The subject has been discussed by J. G. Andersson,[1] who shows that the regolith, becoming saturated with snow water, creeps slowly but bodily down even the gentler slopes. The production of new waste is chiefly dependent upon frost action; so that the two results of a lowering of temperature co-operate and it is not practicable clearly to separate them. The Gila conglomerate, however, on account of the short distance which the bulk of the material was transported,

[1] "Solifluction, a Component of Subaerial Denudation," *Journal of Geology*, Vol. XIV, 1906, pp. 91–112.

and the lack of evidence of highly increased precipitation at the time would seem to be due more largely to frost action.

In conclusion it would appear that where the chief effect of increased cold is an increase of snowfall the change results in an increase in the ratio of transportation to erosion, extending to the limits of such increased snowfall, and not as in the case of increased frost action to an increase of erosion over transportation. The absolute value of both erosion and transportation may increase in both cases.

### EFFECTS OF INCREASED HEAT ON ROCK DISINTEGRATION AND DECAY

It is seen that rock disintegration or physical weathering is at a maximum in regions of exposed rock surfaces, while rock decay is pronounced, on the contrary, where the solid rock is protected from physical changes by the interposition of a layer of soil. The former conditions of bare surfaces are found in mountainous regions, where the steep slopes prevent the retention of soil; or in the deserts, where the absence of ground-water prevents either the formation of an effective vegetable covering or the carrying-forward of the chemical processes of rock decay. The contrary conditions of soil-mantled surface exist where the slopes are moderate or the presence of ground-water gives rise to a vegetable covering sufficient to hold the soil and diminish erosion of its upper surface to a rate equal to that at which decay contributes to the lower strata of the soil. In a climate where rock decay operates strongly there thus arises a very deep soil, partially protecting the deeply buried solid rock from further decomposition and slowing down the rate of decay till it equals the rate of surface ablation, hindered in turn by the luxuriant vegetation also existing in such a region. Both the topographic and climatic factors are thus seen to be fundamental in the result. Under the present topic it is desired to note what effects a climatic variation toward an increase of temperature will have upon these processes of physical and chemical rock destruction which necessarily precede subaerial denudation and are the supplying agents for the diverse materials of sedimentary formations.

*Effects on rock disintegration.*—To produce rock disintegration a high temperature is not necessary but diurnal or hourly variations

of temperature must occur, and the effects will be proportional to the magnitude and rapidity of these changes. As causes tending to magnify these rapid temperature variations may be cited: first, a short transmission of the sun's rays through the atmosphere, implying a thin atmosphere as found on mountains and high plateaus or a high altitude of the sun; second, surfaces at right angles or nearly so to the sun's rays; third, a lack of clouds or of water vapor and to a lesser extent a lack of carbon dioxide in the atmosphere, the former characteristic of continental interiors, the latter of certain geological epochs; fourth, a high value of the solar radiation will increase the disintegrative effects by producing more rapid heating and, as a result of the higher surface temperatures attained, a more rapid cooling when the rock surface passes into shade. Sudden dashes of rain, such as are characteristic of arid and semiarid regions, also operate as a powerful cause of rock disintegration.

To take up these in order: Angot has shown that, although at the summer solstice the quantity of heat received per day at the poles is greater than at the equator, if 0.2 of the solar radiation is absorbed by passing vertically through the atmosphere, then at the poles less reaches the surface of the ground than at the equator.[1] The constancy of the polar daylight at the solstice tends also to prevent rapid temperature changes.

The daily *maximum* insolation of the surface is found to be not far from a constant quantity up to lat. 60, with a maximum at from 30 to 40 degrees. In the higher latitudes, however, this maximum insolation occurring at the summer solstice lasts for but a short time, sinking in the winter to an insignificant quantity. It may be stated then on theoretical grounds that, other conditions being favorable, thermal disintegration may operate strongly to the limits of the polar zones, but that the aggregate effect varies approximately with the latitude, reaching a maximum at the equator and disappearing as an important factor on the polar circles.

Mountain elevations exert an influence upon insolation as important as latitude, a marked difference being noted between the air and

[1] Alfred Angot, "Recherches théorétiques sur la distribution de la chaleur à la surface du Globe," *Ann. bur. central met. de France*, Tome I, 1883, Paris, 1885, B 121–B 169.

ground temperatures, the intensity of solar radiation being 26 per cent. greater on the summit of Mount Blanc than at Paris.[1] Steep rock faces favoring perpendicular action by the sun become of increasing influence in the higher portions of the temperate zones and may even in the arctic, as in Greenland, give a local importance to insolation as a cause of rock destruction, von Drygalski having observed a temperature difference of 20° C. between the air and rock surface.[2]

In regard to the influence of atmospheric composition, it is known that water vapor is the most efficient absorbing medium of the solar heat and also prevents the rapid re-radiation of that part absorbed by the earth's surface, preventing by both means high temperature differences. Clouds also act both by preventing solar radiation from reaching the ground and checking the escape of that already absorbed. These direct effects, taken also in connection with the indirect effects of the presence of water through vegetation, limit insolation as a mode of rock destruction to mountain and desert regions.

Finally, in considering the geological relations of climates to erosion, possible variations of the solar constant of radiation must be considered, an increased intensity of radiation, as previously pointed out, increasing insolative rock disintegration, but only within the limits given by the other conditions. The chief effects of such solar variation would therefore be indirect, by changing the vapor content and cloudiness of the atmosphere, both in geographic location and amount. There are strong reasons for believing, though perhaps hardly yet demonstrated, that an increase in solar radiation would result not only in a slight increase in the mean annual temperature of the earth but also in areal increase of those portions of continental interiors subject to arid and subarid climates. At the same time it is probable that an expansion of the trade-wind belts into somewhat higher latitudes would occur. Certain other regions would also be marked by heavier rainfalls. On the whole, the result would be an accentuation of climates and a marked increase in insolation as a cause of rock disintegration.

In conclusion, it is seen that the control of insolative rock disintegration is largely geographic, being favored in past times by increase

[1] Julius Hann, *Handbook of Climatology*, transl. by R. de C. Ward, p. 233.

[2] *Verdhältniss Geschichte für Erdkunde*, Berlin, 1891, p. 457.

of area and unification of the continental surfaces, giving rise to largely increased areas of continental climates. The indirect action of the sun, however, as just pointed out, is probably an equally potent factor.

According to Murray, one-fifth of the land surface is now desert, having no drainage to the sea.[1] Over this region insolation and eolian abrasion are the chief modes of rock destruction. It may well have happened that in past times of wide epicontinental seas with moist atmospheres and world-wide equable climates, or in times of cold and glaciation, insolation may have sunk to half its present importance as a mode of rock destruction. On the other hand, times of broadened land areas, especially if occurring simultaneously with high solar radiation, may have increased the desert areas beyond their present extent, or at least shifted their limits into higher latitudes, giving rise to peculiar characteristics, such as distinguish particularly the Triassic formations.

The first factor in the acquisition of any such distinctive characters of sediments must depend upon the mode by which the parent rock masses are destroyed. In this respect frost action and insolation act alike, producing rock disintegration without rock decay, both most efficient in regions without heavy precipitation and accentuated by climatic movements away from a temperate condition, but in opposite directions. The subsequent effects of these opposite climates upon the sediments are, however, widely different, as will be made evident on other pages.

A conclusion of some stratigraphic importance is that, if the Gila conglomerate has been correctly interpreted, it is seen that in desert mountains strongly increased frost action with slightly decreased insolation of glacial times is more effective in supplying waste than the present slightly increased insolation with much weakened frost action.

*Effects of increased heat on rock decay.*—Rock decay implies the presence of water, since it is only in its presence that not only hydration but carbonation and oxidation of mineral substances can take place. The problem, then, is in regard to the influence of temperature in promoting rock decay in regions of moist climate. In regard to this von Richthofen is one of the first to observe that—

[1] "Origin and Character of the Sahara," *Science*, Vol. XVI (1890), p. 106.

weathering in fact becomes in large measure a climatic phenomenon. In moist and hot regions it is accomplished easily and rapidly; in hot and dry regions it seems to play an unimportant part, and where high degrees of cold prevail even an abundance of water is unable to produce it in any but an insignificant amount. Beneath the ever-moist moss cushions of Finland and the northern Ural, granite shows undecomposed surfaces.[1]

Russell, from observations in the southern hemisphere, reaches the same conclusions, his statements being as follows:

I may remark from observation that in the Kerguelen and Crozet Islands, in the South Indian Ocean, where a cold, humid climate prevails, and where not only forests but arborescent growths of every description are wanting, there is but little soil, and nothing approaching terra rossa is to be seen. These islands are formed, probably throughout, of dark basaltic rocks, rich in iron, which under more favorable conditions would yield a deep layer of ferruginous soil. Contrast with the Kerguelen Islands others of similar origin in the tropics, as the Samoan Islands, for example. On Kerguelen the highest vegetation is a bitter cabbage which grows mostly in sheltered places along the coast, where it is surrounded with matted ferns and tussocks of moss. The landscape, even on the exceptional days of sunshine, is dark, silent, and gloomy. Among navigators this island is called, not unjustly, the "Land of Desolation." In the Samoan Islands the rank luxuriance of tropical vegetation imparts to the land when seen from the ocean the deep tint of malachite. Wherever the bare earth appears it gleams forth through the overshadowing boughs with a brilliancy that is enhanced by contrast and gives a dash of Pompeian red to the picture of tropical beauty. The soil is deep and rich, and, as in Bermuda, must have been derived entirely from the decay of the rocks forming the islands, which in this case, however, are basaltic, and agree in many ways with the rocks forming the Kerguelen Islands.

The contrast between the present condition of the Kerguelen Islands and that of the Samoan Islands has resulted from differences in climatic conditions. This conclusion would have to be modified, perhaps, should it be found that the former had recently been glaciated. There are abundant observations to show, however, that, in general, islands below latitude 50° south, where winter is almost continuous, are desolate, uninhabitable wilds, and that forty degrees nearer the equator, where perpetual summer reigns, lands formed of nearly identical rock have suffered deep decay and are covered with a rich ferruginous soil, which supports a varied and luxuriant tropical flora.[2]

That rock decay may take place to some extent in cold climates and is frequently absent because of glaciation is indicated by the observa-

[1] *Fuhrer fur Forschungsreisende*, Berlin, 1886, p. 100.

[2] *Subaerial Decay of Rocks and Origin of the Red Color of Certain Formations*, Bulletin 52, U. S. Geological Survey, pp. 30, 31, 1889.

tions of Chamberlin in Greenland and of others in Alaska cited by Merrill.[1] Observation and theory combine, however, in pointing to the greater dominance of the forces of rock decay in warmer pluvial climates and especially in the rainy portion of the torrid zone, the natural activity of the warmer waters being further increased by the organic acids supplied by the large amount of decaying vegetable matter, giving rise to a mantle of rock waste of maximum thickness, thoroughly hydrated and leached by the heavy periodic rains, and thoroughly oxidized by the intervening seasons of dryness. The result is the formation of the red or pink laterite soils of the tropics, and the characteristic red alluvium of the rivers,[2] alluvium poor in soluble constituents.[3]

The effect of moderate cold, such as characterizes the winters of the middle temperate zone, appears to have slight effect upon the erosion of regions in topographic maturity, save that the melting of the winter's snow gives a temporarily higher flood and greater erosive power than would otherwise occur. The summer's heat being less prolonged and intense, gives rise also to less intense oxidation of the soil and less dehydration of the iron oxide, yellows and browns prevailing as soil colors and yellows or grays characterizing the river silts in place of the browns or reds of tropical rivers.

In conclusion, therefore, it may be stated that an increase of temperature away from a temperate mean in regions of heavy rainfall will result in increased rock decay and decreased frost action, and in the opposite characteristics in the case of a temperature decrease. Either variation away from a climatic mean would therefore result in an increase of rock destruction, but of opposite kinds. It is not known, however, but that in the case of an increase of temperature with an abundant rainfall the hold of the vegetation upon the soil may be increased to such an extent as to neutralize the tendency toward more rapid production of rock waste by decay. A close comparative study of valley forms of similar age in the middle and southern Appalachian states in similar rocks would tend to throw light on this problem and show if *erosion* as distinguished from *rock decay*

[1] *Rocks, Rock-weathering, and Soils*, 1897, pp. 278, 279.

[2] Walther, *Einleitung in die Geologie*, p. 815.

[3] Hilgard, *Soils*, 1906, chap. xxi.

is faster in the warmer or cooler climate. In any case, it is evident from the preceding discussion that a series of climatic oscillations involving merely temperature changes would find record in the varying kind and rate of erosion and consequent sedimentation in regions either where this climatic change was between cold and temperate or between temperate and torrid limits.

### Separation of the Topographic and Climatic Factors

As previously stated, under the relations of rainfall and topography to erosion, young, mountainous topography not only gives rise to rapid erosion, but accentuates climatic contrasts, so that a marked distinction may still have opportunity to become developed between the products of erosion of humid and arid mountain regions. The extent to which this is true may be seen by comparing the alluvium of the Rio Grande with that of the Missouri-Mississippi system, where in silts of the same degree of fineness that from the arid region shows a much higher ratio of soluble constituents.[1] The researches of the geologists of India indicate the same contrast between the alluvium of the Indo-Gangetic plain and that of the Brahmapootra in southern Assam.[2] In these examples the material is derived from regions of high relief and rapid erosion. Gravels or cobbles may be deposited under such circumstances nearer the sources, but the production of the conglomerate has involved initial rock-breaking and the production of a considerable quantity of fine material which may occur as a matrix or as separate deposits of clay or silt. These finer materials, as stated, have distinctive characters in each strongly marked climatic province.

It is concluded, therefore, that an examination of the character of the matrix or associated fine beds is of importance in determining the climatic conditions attending the origin of a terrestrial conglomerate or sandstone. This conclusion may be illustrated by contrasting the red sandstones and shales, occasionally conglomeratic, of the Connecticut Valley, with the predominantly gray conglomerates and black shales of the Carboniferous basin of Rhode Island; the two regions being separated by less than fifty miles, and both containing sediments of rather local origin. There are strong evidences in

[1] Hilgard, *Soils*, 1906, pp. 368, 378. [2] Hilgard, *op. cit.*, p. 413.

each case indicating subaerial origin, much of which however is not published. The dominant red color of the whole of the Triassic formation, considered in connection with its feldspathic sandstones indicative of the kind of erosion, mud-cracked shales, disseminated gypsum, and calcite, indicative of conditions of sedimentation, point on the one hand to a subarid climate, while the carbonaceous and leached shales of the Rhode Island coal measures indicate a climate markedly pluvial and cool. It is to be noted that in the Rhode Island basin arkose conglomerates of local origin grade into carbonaceous shales.[1] The conglomerates are extremely abundant and except in the Wamsutta red beds possess a light-gray matrix, while the shales are usually darker in color. Thus the conclusion previously stated is emphasized, that in humid climates, even in regions of rapid denudation and deposit, the finer materials eroded will show greater decomposition and leaching than material of similar fineness, even when derived more slowly from the erosion of surfaces of moderate relief in arid climates. The character of the fine fluviatile or wash detritus *in the region of its origin* may, therefore, be taken as an index of climate. The size or abundance of the coarser material on the other hand forms a measure of the rapidity of erosion, and roughly of the degree of topographic relief. Where the matrix or the form of the cobbles indicates, in association with other evidence, the presence of arid or cold climates, however, disintegration dominates over decomposition, and conglomerates in the region of erosion must be correspondingly coarser and more abundant to indicate the same relief as that of a more rainy region. In rivers sufficiently large so that the erosion and deposition occur in different climatic zones only the finer débris will reach the delta. The chief effect of rugged topography in that case is found in the quantity of sediment and, as will be further discussed in Part III under the topic of the "Effects of Fluviatile Transportation," the evidence as to the climate of the *soucre* becomes more obscure the farther the alluvium is carried.

### Separation of Tectonic and Climatic Oscillations

A full discussion of this topic involves the effects of tectonic and climatic movements upon both transportation and deposition as well

[1] A. S. Packard, "View of the Carboniferous Fauna of the Narragansett Basin," *Proceedings of the American Academy*, Vol. XXXV, 1900, p. 405.

as erosion, subjects which are treated in the following chapters. A partial statement, in so far as erosion is involved, may, however, be made at this place.

It has been seen that climatic variations are potent causes of changes both in the absolute rate of erosion and in the ratio of erosion to the forces removing the waste. While erosion is dependent for its existence upon initial tectonic movements, it has been seen that its varying rate is as dependent upon climatic variations as upon those secondary crustal movements by which occur further uplift or depression or distortion.

Criteria for the distinction of these tectonic and climatic factors are discussed by Davis, in so far as erosion at the headwaters and aggradation of the middle slopes are concerned, and the conclusion is reached that in general the terracing in Central Turkestan seems to be due to climatic variation.[1] The recognition of the importance of climate in building river terraces is in fact a feature in this volume in both the papers of Davis and Huntington. It is only necessary in consequence to summarize briefly certain points which distinguish the upstream terraces built as a result of climatic from those formed by tectonic oscillations. First, the development of terraces on the upper portions of the streams, terraces which die out lower down in the valleys, implies a change in the stream gradients not due to a raising or lowering of the mouth. Regional uplift or depression is excluded in this way. Such a change in gradient in the upper portion of a stream may be due to a local uplift, to a regional warping or a change in the ratio of erosion to transportation brought about by a climatic change. Second, the universality of an epoch of aggradation or degradation in all of the streams of a region is a strong indication of a climatic change, since, as Davis has noted, the crustal bendings necessary to rejuvenate all streams flowing in various directions and finally frequently to bring them back to the initial profile would be extremely complicated and involve an adjustment of subsurface movement to detailed surface form such as is not known to occur and is in fact unthinkable. Although a general similarity in the action of various streams would be expected to occur as a result of climatic

[1] *Explorations in Turkestan*, Publications of the Carnegie Institution, No. 26, 1905, p. 203.

change, this could not be carried down to all details; since it is seen, for instance, that in Arizona, Queen Creek at the present time begins to deposit sediment immediately upon leaving the mountains, while the much larger Gila flowing parallel and but eleven miles to the south flows through the plain as far as Florence in a well-marked valley. In this respect it is to be expected that various streams will behave somewhat after the manner of glaciers, where each responds in its own time and to varying degrees to periods of increased or decreased precipitation of snow. Third, while extremely contrasted climates may leave many distinctive marks in the character of the matrix of even locally transported materials, as shown in the contrast of the Carboniferous of Rhode Island to the Triassic of Connecticut, minor climatic fluctuations cannot be expected to be so recorded. As evidence of such variations, therefore, disturbance of the stream gradient and changes in the coarseness of the detritus must be looked for.

## CONCLUSIONS ON RELATIONS OF CLIMATE AND EROSION

The relative rates of erosion in desert, tropical, and polar climates is a subject upon which there is much diversity of opinion, as Merrill has shown.[1] The difficulties are largely due to the differences in kind of erosion between hot and cold, and arid and rainy climates. The usual geographic remoteness of these extreme types from each other further increases the difficulty. Doubtful conclusions have also sometimes been founded upon the quantities of rock waste present, it being assumed that where rock is deeply decayed, as in the rainy belts of the tropics, it now weathers and erodes rapidly, whereas, on the contrary, the deep regolith may check further decay and the matted vegetation retard the erosion of the surface. Or a traveler may be impressed with the naked mountains and waste-filled valleys of a desert region and conclude that here rock destruction progresses more rapidly than elsewhere on the earth.

A more satisfactory method than that of founding conclusions on quantitative estimates from a few unlike localities is to compare the decay and erosion of unlike climates not with each other but with a third term. For example, the subaerial erosion of arid and rainy regions may be compared with the marine erosion of their coasts, a

[1] *Rocks, Rock-weathering, and Soils*, 1897, pp. 278–85.

common third term, while the influence of warm and cold climates upon erosion may be studied by comparing the erosional rate of glacial times with that of the same regions at present, here the common third term being the topography. This has already been done under the topic of the effects of increased cold.

Turning to the ratio of erosion in arid and rainy climates, as compared with marine denudation, it must be noted that a conclusion should be founded on the average of many instances rather than on a few, since in each the age of the cycle, the attitude and strength of the rock masses, and the strength of the marine erosion will vary. The present discussion must therefore be considered as merely tentative. Very different views have been developed in Great Britain and the United States as to the marine or subaerial production of uplifted and dissected peneplains of Cretaceous and Tertiary age which border the continents, but the growth of knowledge in regard to the capacity of subaerial denudation first in America and more recently in England has given rise to the belief that these are mostly due to subaerial erosion, views confirmed by the application of such criteria as can be applied.[1] In general in rainy climates the rivers are observed to sink rapidly toward base level upon an uplift of the land, to open out interior plains in soft formations, and to dissect deeply the hard ones, while the sea, compelled to work on the outlying formations whether they be hard or soft, cuts inland over a comparatively small area and with increasing difficulty. The problem in such climates is to find good and unquestioned examples of elevated plains of marine denudation comparable to the elevated plains of subaerial origin.

Along the arid coasts of the world very different conditions are, however, found to prevail. To cite examples:

> While the Patagonian plains have an altitude of some three thousand feet at the base of the Andes, they slope very gently to the eastward, and at a distance of some fifty miles from the Atlantic coast, their elevation is more rapidly decreased by a series of escarpments or terrace-like slopes, which face to the eastward and terminate a succession of level plains, decreasing in altitude as one passes from the interior to the coast and finally ending in the lowermost, which, with an average altitude of some three hundred and fifty feet, extends almost uninterruptedly along

[1] W. M. Davis, "Plains of Marine and Subaerial Denudation," *Bulletin of the Geological Society of America*, Vol. VII, 1895, pp. 377–98.

the entire eastern shore, terminating abruptly in the lofty and precipitous cliffs, which for a thousand miles constitute the predominant feature of this coast.

In addition to the characters described above, there may be mentioned as among the more important features of these plains a series of deep transverse valleys that extend from the Andes to the Atlantic. These are all true valleys of erosion, and for the most part they are still occupied by considerable streams.[1]

The prominence of these cliffs indicates the extent to which the waves have planed inland, beginning a new and lower cut upon each uplift of the land. The inadequacy of subaerial denudation in this semiarid climate, with less than ten inches annual rainfall, is indicated by the presence, except in the few river valleys, of the shingle formation left by the retreat of the sea and the fact that the large river valleys are such as derive their waters from the Andes. In more rainy regions the almost level and porous deposits left upon a retreat of the sea also resist rain erosion in the interstream areas for considerable periods of time, but in such regions there is much local drainage and the development of a network of valleys which upon a pronounced uplift permit a rapid erosion.

Along the southwestern coast of Australia for a distance of seven hundred miles the land is terminated by a line of cliffs more than five hundred feet in height unbroken by any stream course and facing a shallow sea which in the Great Australian Bight extends to one hundred and fifty miles from land before attaining a depth of one hundred fathoms. The rainfall is here not over ten inches per year. Such lofty and unbroken walls indicating the dominance of marine over subaerial erosion, it would seem impossible to match in more generously watered regions of theworld; such cliffs as those of Norway and Scotland being cut through on the contrary by valleys of erosion besides forming the front of mountain regions and therefore not necessarily implying a wide horizontal cut for their formation.

The preceding discussion has turned upon the slowness of subaerial erosion in arid climates when acting upon more or less horizontal and débris-mantled formations. An indication of the relative slowness of deflation may also be obtained from southern California and its adjacent islands by noting the remarkable freshness of the naked granite rocks and the sharpness of the post-Pliocene elevated sea-

[1] J. B. Hatcher, *Princeton Patagonia Expeditions*, Vol. I, pp. 214, 215, 1903.

cut cliffs reaching an elevation on San Clemente of 1,320 feet. These according to Lawson are the most remarkable and most magnificent examples of this type of topography which it has ever been his good fortune to behold. He further remarks that such features one might expect to find on a planet, which after their formation, had become stripped of its atmosphere.[1] Similar terraces are found on the coast of northern California, and Lawson regards the whole as due to epeirogenic movement which he considers as sufficiently simultaneous to inaugurate a new geomorphic cycle which is in a nearly uniform state of advancement all along the coast.[2] Under the rainy climate of the coast of northern California, but especially of Oregon, these raised beaches are still conspicuous; but it is noteworthy that they have not called forth such descriptions as those of the arid portions of the coast line, while Diller speaks of the raised beaches of the Oregon coast as being less distinct above eight hundred feet.[3]

It would seem from the above that on the Pacific Coast is an ideal region for comparing the rates and kinds of erosion upon the same initial earth forms, offering an attractive problem for physiographic study.

In conclusion, from the preceding résumé it would appear that an arid climate is an important contributory factor in the development of plains of marine denudation, a factor which so far as the writer is aware has not previously entered into the discussion of the problem of the relative development of plains of subaerial and marine erosion.

Finally, from the discussions under this and preceding topics, the following estimates may be made of the relative rates of erosion under different climates upon average rock materials in a state of topographic maturity. From such a brief study such a statement is clearly nothing but an estimate. Proceeding from what is thought to be the less rapid to the more rapid they would be—

[1] *The Post-Pliocene Diastrophism of the Coast of Southern California*, Bulletin of the Department of Geology, University of California, Vol. I, No. 4, 1893, p. 129.

[2] *The Geomorphogeny of Northern California.* Bulletin of the Department of Geology, University of California, Vol. I, No. 8, 1894, p. 270.

[3] *Coos Bay Folio*, U. S. Geological Survey, p. 1, 1901.

FOR ARID CLIMATES

1. Warm-temperate arid: moderate sun and wind action.
2. Tropical arid: strong sun and wind action.
3. Cold-temperate arid: strong frost and wind action.

FOR RAINY CLIMATES

1. Temperate rainy: moderate mechanical and chemical disintegration.
2. Tropical rainy: moderate mechanical, intense chemical disintegration.
3. Subpolar rainy: intense mechanical, moderate chemical disintegration.

The evidence in regard to the relative position of the varieties of rainy climate does not seem to be as secure as that in regard to the arid climates.

In comparing the rainy climates to the arid it is thought that, on the whole, the rainy climates are the greater destroying agents, but so many factors enter in the final result that it is thought that *a change toward semiaridity will hasten instead of retard erosion* through a weakening of the vegetal covering and a concentration of rainfall. The local accumulations of waste resulting from a movement toward aridity, while apparently indicative of great erosion, should really from their mere presence not be allowed to influence the judgment.

Recent geological times have been marked by climatic oscillations of great magnitude resulting in synchronous erosional and sedimentary oscillations. In past geological times other climatic oscillations must be presumed to have taken place frequently, though normally of much less intensity than during the past ice age. The sedimentary effect of climatic variations as well as stable climates is therefore of geological importance. From the previous discussion it would appear that any variation *from* a temperate climate, either arid or pluvial, would involve a temporary, abnormally rapid increase of rock waste until the regolith had become adjusted to the new conditions. Any variation *toward* these temperate means, such as the normal changes in the temperate zones since glacial times, will result, on the other hand, in a rapid slackening of rock destruction. Through geological time, therefore, the slowly but perpetually fluxing climates would

find a delicate response in the rates of erosion and the kinds of material supplied to the streams. With each climatic oscillation the delicate balance of erosion to stream transportation is thrown out of equilibrium and a wave of disturbance *originating at the headwaters* is sent to, and even beyond, the river's mouth. Even when the nature of the climatic changes at the distant source cannot be determined, they should still be recognized as possible factors in those lithologic distinctions which characterize the successive stages of a sedimentary formation.

The influence of climatic changes upon sedimentation has been tacitly recognized by certain leading writers, either as a hypothesis to account for a regular alternation of marine strata, as has been done by Gilbert;[1] or, through the use of gravel terraces as a means of correlation between glaciated and unglaciated regions. In the latter case they have been distinctly recognized and classified by Davis and Huntington as terraces of climatic origin, and criteria for their distinction have been devised. The relations of climate to erosion appear to be so sensitive, however, and so important, as a causal factor in the variations of stratified rocks, that it would seem desirable to distinguish it clearly as a separate cause, and call special attention to it, as is here done, as of co-ordinate importance with minor movements of the earth's crust. The lack of conscious recognition of this factor has without doubt caused many minor sedimentary changes, and even some greater ones, to be taken as evidence of earth movement, when climatic changes have at least entered as important contributory factors.

Before these waves of climatic effect find record in the strata, however, they are modified by the accompanying variations in the power of transportation and the changes which the sediments undergo before burial on the surface of the flood-plain or bottom of the shallow sea, modifications which will be discussed in the two succeeding parts.

[1] "Sedimentary Measurement of Cretaceous Time," *Journal of Geology*, Vol. III, 1895, pp. 121–27.

[*To be continued*]

# *Reviews*

*The Earth a Failing Structure.* Presidential Address before the Philosophical Society of Washington. By JOHN F. HAYFORD. *Bulletin of the Philosophical Society of Washington, D. C.*, Vol. XV, pp. 57–74, December, 1907.

The title of the address clearly expresses its central thought. The endeavor is to show that the earth is not a competent elastic structure. The main basis of argument is that, in the past, the earth has yielded frequently, if not continuously, to the stress-differences brought to bear upon it, and that it is still yielding. This yielding is repeatedly spoken of as non-elastic, but specific evidence is not given that the yielding is strictly of the non-elastic type. Every geologist will accept the fact of yielding without hesitation, but some of us might be disposed to question the precise method by which the yielding takes place, for it is just at this point that discrimination now halts for adequate evidence, and it is just here that some of the greatest advances in deformation appear now to be on the verge of realization. If the conclusion that the earth is a failing structure can be safely based on the gross observation that it, or parts of it, have yielded to stresses in the past, there can be little ground for difference of view, and little occasion to regard the view as new except in its form of expression, and we may all acquiesce in the striking text of the address.

At the same time it may be said with equal deference to observed fact that the earth is a *creative* structure and that it long has been and still is *generating* structural strength, elasticity, and rigidity. On the whole, its creative activities seem to have been quite as pronounced as its failing tendencies; its acquisitions of competency to have been quite as great as its exhibitions of incompetency.

Perhaps nothing better represents a failing structure, in the sense of the address, than a glacier which, under normal conditions, is ever yielding to the stress of gravity. And yet if one wanted to select a cubic foot of ice which had the maximum of strength and rigidity and the highest elastic limit, he would seek it at the lower end rather than the upper end of the glacier. The structural competency of the ice normally increases in about the proportion in which it has previously failed as a competent elastic structure, if one so interprets its yielding.

If a sandstone be sufficiently stressed, it will perhaps seem to fail as a structure, but the quartzite into which it might pass would doubtless

show under test greater strength, greater rigidity, and a higher elastic limit, than the original sandstone. A plastic shale, if duly forced to "fail" often enough and sufficiently, might, like certain of our shopmen, come out of the process a highly elastic schist. If ten million blocks of earth-material, so distributed throughout the earth as best to represent its structural competency, could be tested today and the results compared with a similar test made in Cambrian times, the elastic competency would quite certainly be found to be as great now as then. There is some presumption that it would be rather greater.

The engineer in dealing with an artificial structure properly enough proceeds on the assumption that there is present a certain modicum of structural competency, and that when this is once broken down that ends the matter. The earth cannot be dealt with advisedly in this way. The constant regeneration of strength, of rigidity, and of elasticity, under appropriate conditions, is as vital a factor in the earth problems as is the breaking-down of such acquisitions of these properties as had been inherited from the previous constructive processes.

There are many things in the address which are suggestive and helpful, and in so far as they lead on to more critical studies they are heartily to be welcomed. The reviewer would suggest, however, as a running mate to this address, one on the earth as a generative structure. T. C. C.

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*Schmidt's Geological Sections of the Alps.*

American geologists who are interested in modern interpretations of Alpine structure will find a valuable series of colored sections in several pamphlets by Professor C. Schmidt of Basel, as follows: (1) *Bild und Bau der Schweizeralpen*, which appeared as a supplement to Vol. XLII of the Swiss Alpine Club, 1907 (Basel: Finckh. Fr. 5), contains, besides a beautifully illustrated text, a small geological map and a remarkable group of sections illustrating the extreme extension now given to the idea of overthrust folds. (2) *Führer zu den Exkursionen der deutschen geologischen Gesellschaft im südlichen Schwarzwald, im Jura und in den Alpen, August, 1907*, by Schmidt, Buxtorf, and Preiswerk (Stuttgart: Schweizerbart. M. 5), containing a number of more detailed sections, as well as the group of general sections. (3) *Ueber die Geologie des Simplongebietes und die Tektonik der Schweizeralpen* (*Eclog. geol. Helv.*, IX), with a number of detailed sections and a general geological map of the Alps between St. Gotthard and Mont Blanc. (4) *Tektonische Demonstrationsbilder* (to be had of the author. Fr. 1), with some of the same Alpine sections and several additional sections for the Vosges and the Schwarzwald.

W. M. D.